REQUEST FOR MARINE MAMMAL PROTECTION ACT SECTION 120 AUTHORIZATION TO REMOVE CALIFORNIA SEA LIONS FROM THE WILLAMETTE RIVER

SUBMITTED BY

OREGON DEPARTMENT OF FISH AND WILDLIFE

OCTOBER 5, 2017

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I. APPLICATION

The Oregon Department of Fish and Wildlife (ODFW) submits this application under Section 120(b)(1)(A) of the Marine Mammal Protection Act of 1972 (MMPA; 16 U.S.C. §1361 et seq.) to the National Marine Fisheries Service (NMFS) for the intentional lethal removal of California sea lions (CSLs; *Zalophus californianus*) in the Willamette River which are having a significant negative impact on the recovery of Pacific salmon and steelhead (*Onchorynchus* spp.) listed as threatened under the Endangered Species Act of 1973 (ESA; 16 U.S.C. §1531 et seq.). The affected stocks are Upper Willamette River (UWR) winter steelhead (*O. mykiss*; ESA threatened) and UWR spring Chinook salmon (*O. tschawytscha*; ESA threatened).

Section 120(b)(2) requires any application to include a means of identifying the individual pinniped or pinnipeds, and a detailed description of the problem interaction and expected benefits of the taking. Details are provided below under "Considerations", but briefly:

- Predatory CSLs will be individually identified based on natural or applied features that allow them to be individually distinguished from other CSL.

- The problem interaction involves the predation of UWR steelhead and UWR spring Chinook salmon by CSLs between Willamette Falls and the mouth of the Clackamas River between November 1 and August 15.

- The expected benefit of the requested removal authority will be to eliminate this recent, unmanageable (without removal authority), and growing source of mortality that has jeopardized Oregon's ongoing efforts to recover ESA-listed salmonids in the Willamette River basin. Our analysis suggests that if current levels of predation continue, the probability of extinction for the three major UWR steelhead population's ranges from 20-64%; if predation was eliminated, the probability of extinction decreases to <5%.

We propose to lethally remove individually identifiable CSLs that are having a significant negative impact on the above ESA-listed salmonids. We define such animals as those that meet at least one of the following two criteria:

- They have been observed eating at least one salmonid between Willamette Falls and the mouth of the Clackamas River between November 1 and August 15 of any year.

- They have been observed between Willamette Falls and the mouth of the Clackamas River on a total of any three calendar days (consecutive days, days within a single season, or days over multiple years) between November 1 and August 15 of any year.

In addition, we propose to conduct removals according to the following conditions:

- Annual removals will be limited to no more than one percent of the CSL Potential Biological Removal[1] (PBR) level.

- When possible, we will facilitate the transfer of eligible sea lions to pre-approved holding facilities for permanent captivity.

- Capture, holding, and euthanasia protocols will be based on the review and approval of an Institutional Animal Care and Use Committee (IACUC).

- Removals will not be contingent on any non-lethal hazing activities as they have repeatedly been shown to have no long-term beneficial effects at this and other similar locations.

II. BACKGROUND

In 1972, The U.S. congress enacted the MMPA to provide protection for all marine mammals in U.S. waters, ending centuries of exploitation for many species. As one result, the U.S. stock of CSLs has increased from fewer than 75,000 individuals to recently as many as 296,750. The U.S. stock is now likely within its Optimum Sustainable Population (OSP)[2] range, thus meeting the conservation objectives of the MMPA. Over this same period, many salmon and steelhead populations in the Pacific Northwest experienced significant declines in abundance and were consequently listed as threatened or endangered under the ESA. These declines were initially and primarily a result of multiple factors unrelated to predation by pinnipeds. However, in areas where salmonid abundance is low, even a modest increase in predation by pinnipeds can result in serious negative impacts to the survival and recovery of individual salmonid populations.

The Willamette River basin in Oregon has two such ESA-listed salmonid stocks: UWR winter steelhead and UWR spring Chinook salmon. The primary reason for listing these stocks was the effect of dams for hydropower and flood control, but tributary and estuarine habitat degradation, harvest, and hatcheries also contributed to the declines. To address the cause of the declines, the State of Oregon and many other agencies and organizations have been involved in efforts to restore salmon and steelhead populations in the Willamette River for decades. Recovery plans

[1] Potential Biological Removal (PBR) Level: defined by the Marine Mammal Protection Act as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population.

[2] Optimum Sustainable Population (OSP): defined by the MMPA section 3(9), with respect to any population stock, the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element. (16 U.S.C. 1362(3)(9)). Optimum Sustainable Population is further defined by Federal regulations (50 CFR 216.3) as is a population size which falls within a range from the population level of a given species or stock which is the largest supportable within the ecosystem to the population level that results in maximum net productivity. Maximum net productivity is the greatest net annual increment in population numbers or biomass resulting from additions to the population due to reproduction and/or growth less losses due to natural mortality.

have been developed for these stocks to reduce threats to recovery by restoring important habitat, improving dam passage survival, reforming hatchery programs to assist wild populations, and reshaping fisheries by focusing on selectively harvesting hatchery fish. Oregonians have supported and borne the costs of restoration efforts of these salmonid resources because of their cultural significance, their important role in the ecosystem, and their economic value.

Now—as with Ballard Locks in the 1980s and Bonneville Dam in the 2000s—Willamette Falls is the latest location where a relatively small but growing number of CSLs have learned to exploit an area where migrating salmon and steelhead are particularly vulnerable to predation as they congregate at the falls during their upstream spawning migration[3]. Concentrated predation by CSLs on these depressed fish runs has put their recovery at risk, even to the point of extinction. Options for managing these locally over-abundant but protected marine mammals are few. For example, over twenty years of experience with non-lethal deterrents has shown these methods to have no long-term effect on reducing predation. We are therefore left with the only statutory tool currently available to provide relief: Section 120 of the MMPA.

III. APPLICATION CONSIDERATIONS—SECTION 120(d)

A. *Sec. 120(d)(1)— population trends, feeding habits, the location of the pinniped interaction, how and when the interaction occurs, and how many individual pinnipeds are involved;*

1. Population status of California sea lions in the U.S.

According to the 2016 U.S. Pacific Marine Mammal Stock Assessment (Caretta et al. 2017), the U.S. stock of California sea lions was not listed as "endangered" or "threatened" under the ESA, nor "depleted" under the MMPA. The population was estimated to be 296,750 animals and the Potential Biological Removal (PBR) level was 9,200 animals per year. Because the estimated total human-caused mortality of at least 389 animals per year was less than PBR, the stock was not considered "strategic" under the MMPA.

2. Population trends of California sea lions at Willamette Falls

Archaeological evidence indicates that California sea lions were present along the Oregon coast during at least the last 3,000 years (Lyman 1988) but there is no similar evidence of their presence in the lower Columbia River or its tributaries (Lyman et al. 2002). The first known record of a CSL at Willamette Falls (128 miles upstream from the ocean) is from the 1950s, when a single CSL was shot below the falls, with the next subsequent record not occurring until 1980 (Beach et al. 1985). By the mid-1990s, however, there were frequent observations of CSLs in the Willamette River where they were observed foraging for winter steelhead and spring Chinook salmon below Willamette Falls (ODFW, unpublished data).

[3]Steller sea lions (*Eumetopias jubatus*), and to a much lesser extent Pacific harbor seals (*Phoca vitulina*), are occasional visitors to Willamette Falls. Their impact on listed salmonid stocks is unknown at this location.

ODFW began a predation monitoring program at Willamette Falls in 1995 followed by a CSL branding program at Astoria in 1997 to monitor foraging behavior throughout the Columbia River basin. Intermittent predation monitoring at the falls by ODFW occurred from 1995-2003, after which the agency's limited resources shifted to Bonneville Dam on the Columbia River, to address a significant increase in California sea lion predation on salmonids in the early 2000s (e.g., Keefer et al. 2012). Attention soon returned to Willamette Falls, however, as winter steelhead passage declined, coupled with an increase in sea lion activity.

Monitoring from 2009-2012 by Portland State University (PSU) and from 2014-2017 by ODFW demonstrates that California sea lion abundance has increased from the late 1990s and early 2000s and is continuing to increase annually (Figure 1).

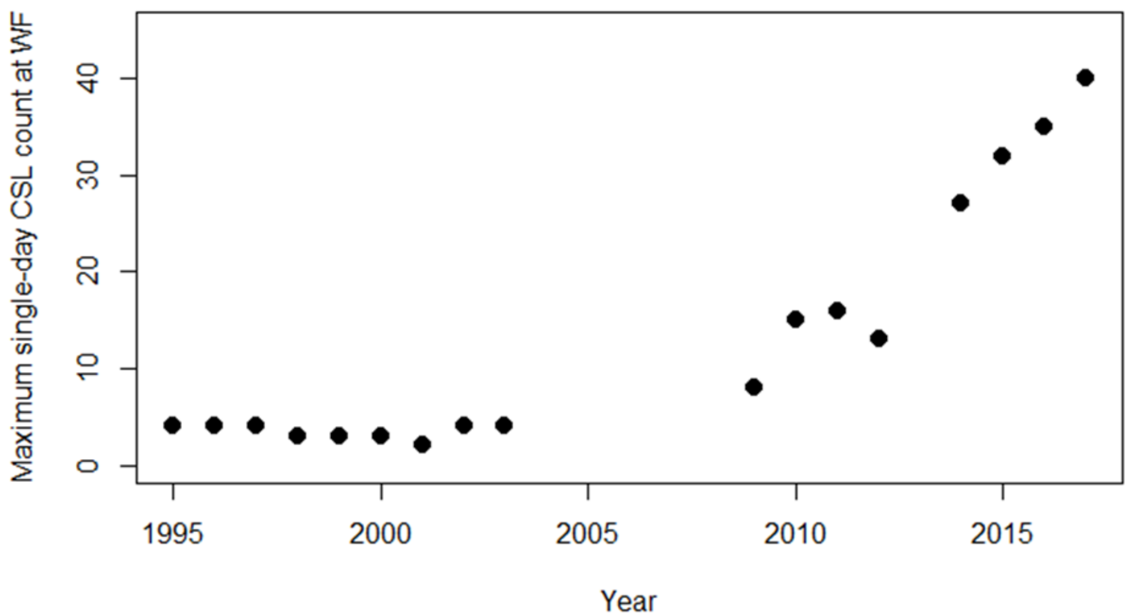

Figure 1. Maximum single-day CSL count at Willamette Falls by year. Monitoring from 1995-2003 and 2014-2017 was conducted by ODFW; monitoring from 2009-2012 was conducted by PSU.

While CSL activity at Willamette Falls has been increasing since at least 2009, it likely was accelerated by recruitment from the dramatic influx of animals into the lower river starting in 2013 (Figure 2). Given the increasing trend in CSL abundance in the Columbia Basin and the Willamette River specifically, there is no reason to expect CSL numbers at Willamette Falls to decline in the absence of intervention.

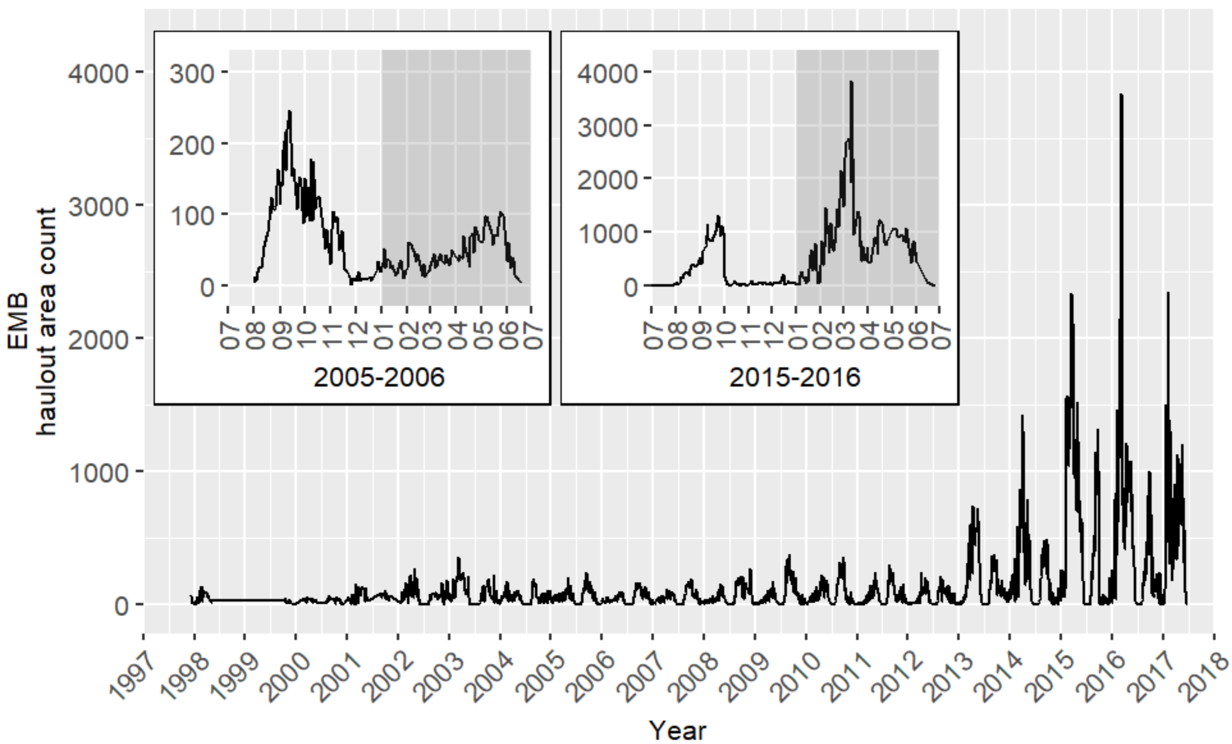

Figure 2. Time series of California sea lion haul-out area counts at the East Mooring Basin (EMB) in Astoria from December 1997 to June 2017. Insets illustrate the changes in magnitude and seasonality of California sea lion occurrence over the study period (x-axis denotes month; note difference in magnitude of counts on the y-axis scale between the two inset figures).

3. Feeding habits of California sea lions

California sea lions are opportunistic predators that feed on a wide variety of fish and squid. Their diet is diverse and varies seasonally and by location. Some of the common prey within their breeding range in California are Pacific whiting, anchovy, market squid, and rockfish (Scheffer and Neff 1948, Fiscus and Baines 1966, Fiscus 1979, Antonelis et al. 1984). In Washington and Oregon, their diet consists primarily of seasonally abundant schooling species such as Pacific whiting, herring, Pacific mackerel, eulachon, salmon, squid, Pacific lamprey, codfish, walleye pollock, and spiny dogfish (Beach et al. 1985, Brown et al. 1995, Riemer and Brown 1997). Movements and distribution of CSL are often correlated with spawning aggregations of various prey (e.g., Pacific whiting, herring, salmonids) and indicate the ability of CSL to cue into locally abundant concentrations of these species (NMFS 1997).

At Willamette Falls, direct observations of surface-feeding events by CSLs from 2014-2017 demonstrate that approximately 85% of prey brought to surface are salmonids (Table 1), followed by lamprey (14%), and unidentified or other species (1%). Similarly, an analysis of 35 scat and 14 spew samples collected below Willamette Falls from 2016-2017 suggests that the two most common prey species are salmonids (occurring in 78% of samples) and lamprey (60% of samples), whereas juvenile salmonids (which can be consumed underwater) and other or unknown species only occurred in a few samples (Table 2).

Table 1. Observed predation by California sea lions at Willamette Falls, 2014-2017.

	Observed predation					% of observations				
Prey	2014	2015	2016	2017	Total	2014	2015	2016	2017	Total
Salmonids	959	1139	1001	753	3852	86.7%	85.2%	83.8%	82.7%	84.7%
Lamprey	126	175	182	145	628	11.4%	13.1%	15.2%	15.9%	13.8%
Other/unk.	18	21	11	12	62	1.6%	1.6%	0.9%	1.3%	1.4%
Sturgeon	3	2	0	0	5	0.3%	0.1%	0.0%	0.0%	0.1%
Total	1,106	1,337	1,194	910	4547	100%	100%	100%	100%	100%

Table 2. Scat (feces) and spew (regurgitation) analysis of 49 samples collected at the Sportcraft Landing haul-out area from 10/26/2016-4/24/2017. Samples were most likely from California sea lions although the presence of some Steller sea lion samples cannot be ruled out.

Date	Scat	Spew	Salmonid, non-juvenile	Lamprey spp.*	Salmonid, Juvenile	Unknown/ other
10/26/2016	1		1	1		
12/1/2016	1	1	2	1		
12/13/2016	1		1			
1/19/2017	2		2			1 (mackerel)
1/24/2017	2		2	1		
1/26/2017	2		2	1		
2/1/2017	7		7	3	1	
2/2/2017	4		4			
2/10/2017	2		2	2		
2/16/2017	1		1	1		
2/24/2017	1		1			
3/1/2017	2		2	2		
3/15/2017	4		4	3		1 (unknown)
3/31/2017	4	1	5	2	1	
4/4/2017	1	1	1	1		1 (rockfish)
4/14/2017		9		9		
4/24/2017		2	1	2		
Total (%)	35	14	38 (78%)	29 (59%)	2 (4%)	3 (6%)

*Includes primarily fish identifiable as Pacific lamprey but also other lamprey remains that could not be identified to the species level.

4. Location of the pinniped-fish interaction

The pinniped-fish interaction in question occurs at Willamette Falls and areas downstream on the Willamette River (Figure 3). Willamette Falls is a combination natural falls and hydroelectric dam located approximately 42 km (26 mi) upriver from the confluence with the Columbia River and 206 km (128 mi) from the ocean. While pinniped predation on salmonids likely occurs throughout this 206 km long distance, supporting data for the purposes of this application comes largely from the 4 km (2.5 mi) long reach between the mouth of the Clackamas River and the base of Willamette Falls. Besides foraging extensively for salmonids in this reach, CSL haul out here, primarily on docks at the upstream edge of the Sportcraft Landing Moorages. Candidate CSLs identified for removal would be based on data from this area although removals themselves could occur wherever it was safe and logistically feasible to do so (e.g., Astoria, Bonneville Dam), other than the breeding grounds.

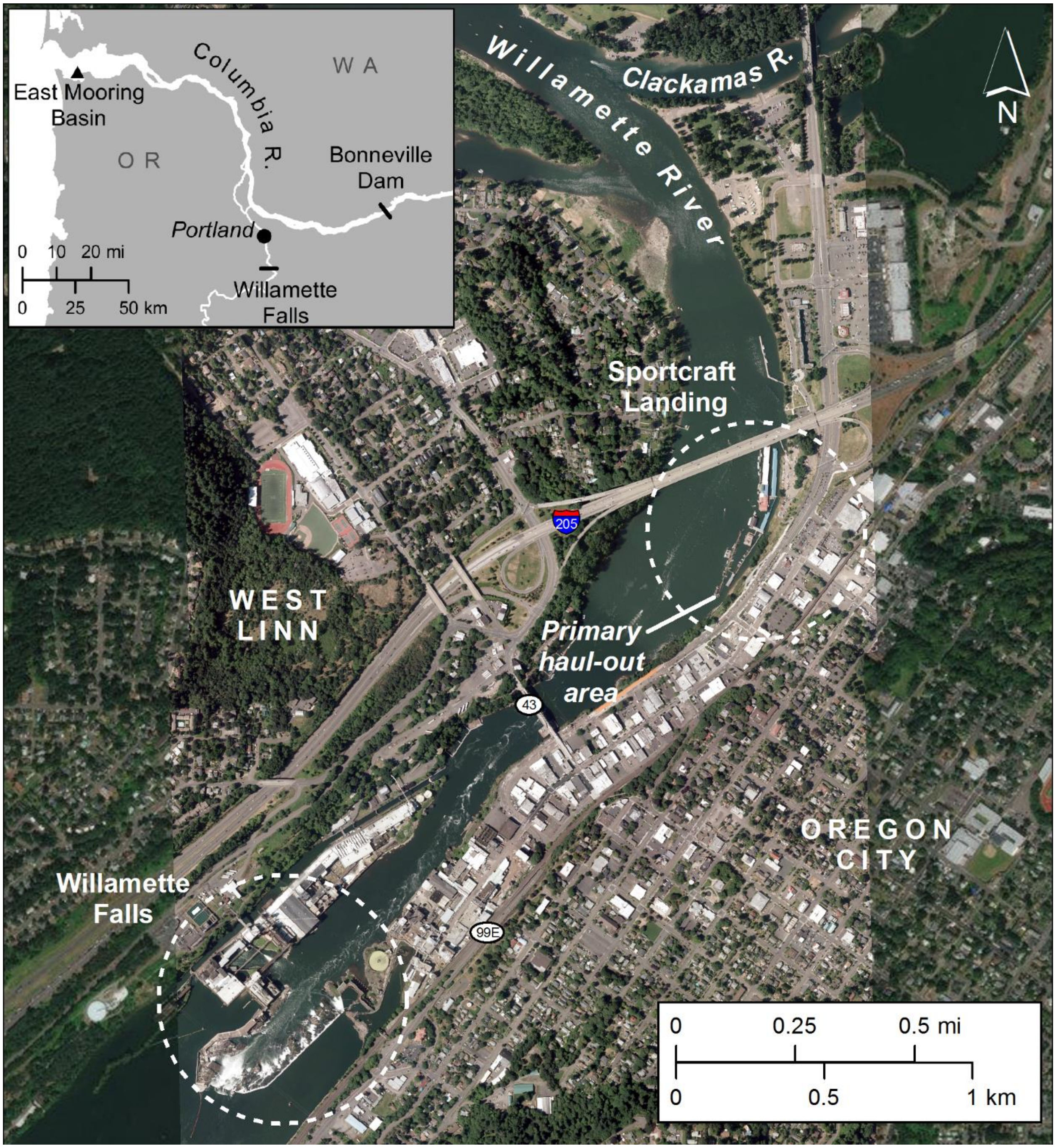

Figure 3. Map showing Willamette Falls to the mouth of the Clackamas River. Inset map shows location of falls relative to Columbia River including Bonneville Dam and the haul-out area at the East Mooring Basin in Astoria.

5. Timing of the pinniped-fish interaction

California sea lions have been observed at Willamette Falls from August to June. The UWR winter steelhead run passes Willamette Falls from November 1-May 31 and the UWR spring

Chinook salmon run passes from February 1-August 15. However, both runs may stage below the falls prior to these dates and thus may be exposed to predation earlier than their calendar-based run dates.

6. Number of individual pinnipeds involved

Estimating the number of individual CSLs involved in this or any similar interaction is problematic given that many animals are not individually identifiable nor do they all haul out at the same time and location which would facilitate counting. However, daily, weekly, and seasonal maximum counts provide a minimum estimate of the number of animals present in the area (e.g., Figure 1 and 4).

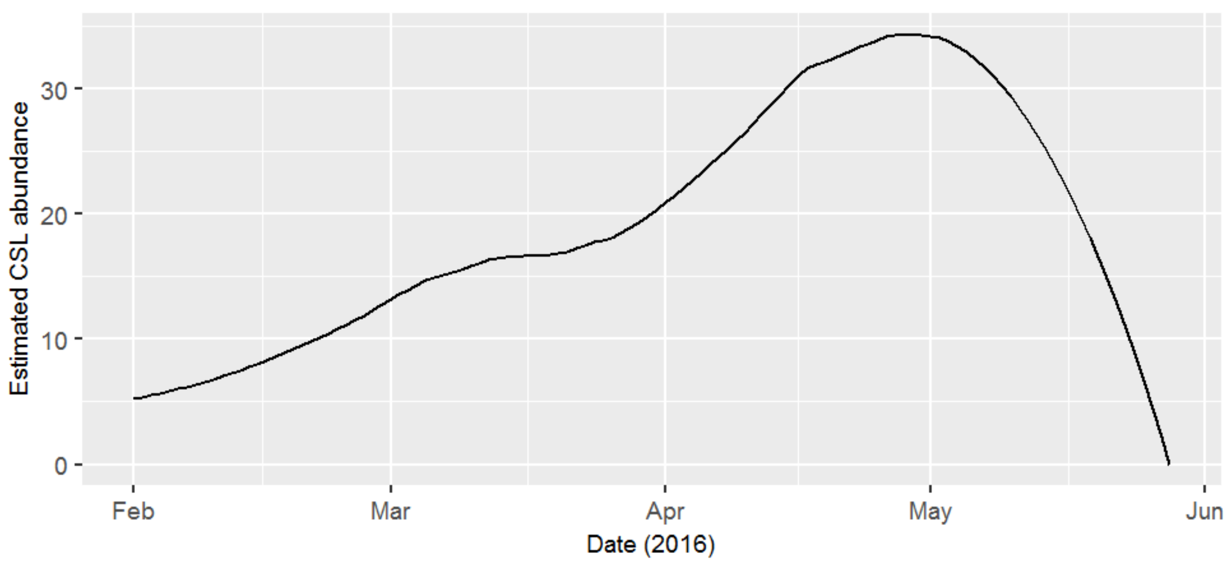

Figure 4. Estimated daily California sea lion abundance at Willamette Falls in 2016 based on loess model fit to weekly maximum count data (Wright et al. 2016).

Because there is turnover in individuals over the season, the actual number of animals utilizing the area is larger than any one maximum count. We attempted to estimate the total number of animals in 2016 by installing automated cameras at the main haul out site. Counts gleaned from thousands of these images were combined with observations from foraging areas to estimate trends in relative abundance within a given season (see Wright et al. 2016 for details). From this we estimated that the total number of individuals that occurred at Willamette Falls throughout the entire season was 37% higher (i.e., 48 animals) than the single-day maximum count of 35 (see Wright et al. 2016 for details). We repeated the camera work in 2017 but image processing is still pending. The general pattern observed in 2016, however, was consistent with what we observed in in 2017 as well as previously in 2014 and 2015.

Resights of branded animals can also shed light on the number of individuals involved. Since 1997, ODFW has branded over 3000 CSLs in Astoria, Oregon, and later (in cooperation with WDFW) at Bonneville Dam on the Columbia River. A total of 39 of these branded animals were observed at Willamette Falls from 2014-2016, the majority of which have been observed at this site in multiple years (Table 3). For example, C742 was initially branded in Astoria on 9/24/2007 and has since been observed at Willamette Falls nearly every year for nine years. Notably, just over one-half of these branded animals have also been observed at Bonneville Dam on the Columbia River, and one-quarter are on the list for permanent removal under the existing Bonneville MMPA Section 120 letter of authorization (LOA).

Table 3. California sea lion brands detected at Willamette Falls during 2014-2016 and whether they had been seen previously (2009-2013) and/or subsequently (2017). Light-shaded cells with "NA" indicate animals branded subsequent to resight year; darker-shaded cells indicate animals that were euthanized at Bonneville Dam prior to that resight year.

Brand	Brand date	Earliest known sighting at falls*	2014 (n = 19)	2015 (n = 23)	2016 (n = 26)	2017**
C257	2002-03-15	2009	X			
C742	2007-09-24	2009	X	X	X	X
C885	2008-09-29	2009	X	X	X	X
C942	2009-04-24	2011	X			
C997	2009-09-08			X	X	
U65	2010-05-14		X	X		
U68	2010-05-14			X		
U78	2010-05-16		X	X	X	
U117	2010-08-26	2013	X	X	X	X
U110	2010-08-26		X	X	X	
U111	2010-08-26			X	X	X
C010	2011-03-31	2011	X	X		
U163	2011-05-18		X	X	X	
U190	2011-08-29		X			
U253	2012-08-21	2013	X	X	X	X
U278	2012-09-11	2013	X	X	X	X
U322	2013-03-24				X	
C025	2013-04-23		X	X		
C026	2013-04-23		X		NA	NA
C030	2013-04-30			X		
U404	2013-05-22		X	X	X	X
U449	2014-02-25	NA	X			
C036	2014-04-09	NA	X	X	NA	NA
C038	2014-04-16	NA	X			
C039	2014-04-16	NA		X	NA	NA
U605	2014-08-19	NA	NA	X	X	X
U727	2015-02-18	NA	NA	X	X	X
U835	2015-03-11	NA	NA	X	X	X
C057	2015-04-07	NA	NA	X	X	X
C064	2015-04-08	NA	NA	X	X	X

C099	2015-04-22	NA	NA		X	X
1-82	2015-05-19	NA	NA		X	X
1-64	2015-05-19	NA	NA		X	X
1-63	2015-05-19	NA	NA		X	X
U942	2015-08-12	NA	NA	NA	X	X
U971	2015-08-24	NA	NA	NA	X	X
X139	2015-09-22	NA	NA	NA	X	X
X297	2016-02-29	NA	NA	NA	X	X
1-89	2016-05-03	NA	NA	NA	X	X

* Based on records from Portland State University and/or ODFW.

** Draft data; additional brands were observed in 2017 but are not shown here.

The collective evidence from 2014-2017 leads us to infer that during the early part of the winter steelhead run there are at least 10 CSLs consistently involved but throughout the entire salmon and steelhead migration as many as 100 CSLs are responsible for predation on listed salmon and steelhead at the falls. To put those numbers in context, Figure 5 shows the relative numbers of CSL for a variety of demographic and spatio-temporal categories. In this context, the pool of problem animals at Willamette Falls represents no more than 0.2% (i.e., 100 / 50K) of the seasonal population of migratory sub-adult and adult males in the Pacific Northwest and no more than 0.03% of the total population.

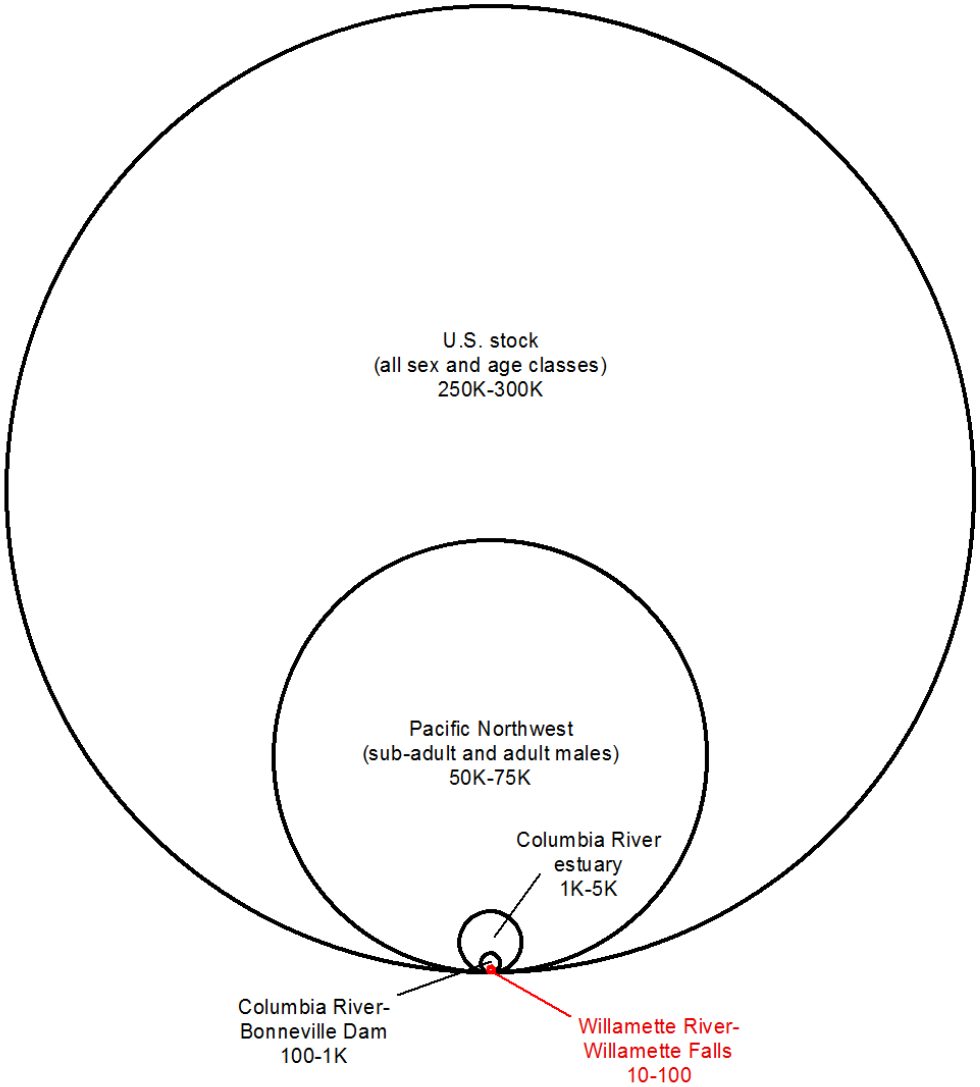

Figure 5. Illustration showing the relative number of California sea lions at varying spatio-temporal scales. The area of each circle increases proportional to the change in the lower bound on abundance (i.e., from smallest to largest, area increases by a factor of 10, 10, 50, and 5 respectively). The Pacific Northwest subset and below indicates sub-adult and adult male abundances during peak spring months.

B. *Sec. 120(d)(2)— past efforts to nonlethally deter such pinnipeds, and whether the applicant has demonstrated that no feasible and prudent alternatives exist and that the applicant has taken all reasonable nonlethal steps without success;*

1. Nonlethal deterrent methods

Non-lethal methods to deter pinnipeds from feeding on fish or using specific areas are described in NMFS (1997), Fraker and Mate (1999), Bowen (2004), and Scordino (2010; see Appendix 1). These methods include: seal bombs (underwater firecrackers), shell crackers (pyrotechnics discharged from a 12 gauge shotgun), aerial pyrotechnics (screamer rockets, poppers), acoustic deterrents (AHDs, ADDs), pulsed power, taste aversion, predator sounds (killer whales), predator models (killer whales), vessel chase, rubber projectiles, physical barriers or exclusion devices (e.g., at fish ladder entrances), electric barrier, and translocation.

2. Nonlethal deterrent efforts at Willamette Falls

In response to the arrival of CSLs at Willamette Falls in the late 1990s, ODFW installed Sea Lion Excluder Devices (SLEDs) at each of the fish-way entrances and intermittently hazed animals with shell crackers and seal bombs under authority provided by MMPA Section 109(h) which allows government officials to use non-lethal means to remove (take) nuisance marine mammals as part of official duties. With the increase in CSL activity in the late 2000s, ODFW conducted increasingly intensive nonlethal hazing operations during 2010, 2011, and 2013 (there was no hazing during 2012 due to a state hiring freeze) to move sea lions downriver and away from the falls and fish ladders (see Table 4 for a summary of the program).

Table 4. Summary of ODFW hazing efforts at Willamette Falls from 2010-2013.

	Effort			Deterrents			Animals Exposed to Hazing	
Year	Start	End	Days	Shell Crackers	Rubber projectiles	Seal bombs	CSLs	SSLs
2010	3/26	4/30	8	~800	~30	~400	NA	0
2011	2/7	4/26	49	6,863	135	2,771	860	0
2013	2/4	4/29	81	10,976	601	8,042	1,871	45

Hazing from 2010-2013 typically involved one hazer operating from atop the fish ladder and other mill structures adjacent to the falls in conjunction with three hazers operating from a boat. The standard practice was to have the hazer on the fish ladder shoot shell crackers to move any observable sea lions away from the fish ladder and towards the boat. The hazers in the boat would then move the sea lions downstream and away from the falls and fish ladders using shell crackers and seal bombs.

While deterrent efforts had some short-term success in reducing predation at specific locations and times, they were unable to eliminate predation or reduce the sea lion presence in the area. As has been found in past hazing efforts in other locations, sea lions generally acclimated to hazing efforts and often continued foraging despite all hazing efforts. For example, once hazing efforts ended for the day, sea lions quickly resumed their typical foraging behaviors. Additionally, numerous attempts to prevent animals from hauling out on docks at Sportcraft Landing were similarly unsuccessful.

3. Efficacy of nonlethal deterrents

In his exhaustive review of pinniped deterrent methods, Scordino (2010) concluded that

"In most cases, non-lethal deterrence measures were found to have limited or short-term effectiveness because pinnipeds appeared to learn to avoid or ignore the measure applied. The use of noise or other stimuli that cause a startle and flight response in pinnipeds were found to cause initial fright reactions and short-term avoidance, but the measures were eventually ignored or avoided by pinnipeds that had prior exposure. During many years of attempting to deter California sea lions from foraging on steelhead at the Ballard Locks (Scordino and Pfeifer 1993), NMFS and WDFW found that non-lethal deterrence measures had to inflict physical pain to the pinniped in order to effectively deter the pinniped beyond the initial startle response especially when the pinniped had previously foraged on salmonids at the site (NMFS 1996). Otherwise, the only effective measure was removal of the pinniped. ODFW and WDFW had the same results in attempting to deter California sea lions from Bonneville Dam (Brown et al. 2008)."

Additionally, in 2010 the Pinniped-Fishery Interaction Task Force for the Bonneville Dam Section 120 program was tasked by NMFS to address the following question:

Does non-lethal hazing appear to be an effective aid in reducing sea lion predation on salmonids in the area? Should non-lethal efforts be modified (increased, reduced, or re-directed) to improve effectiveness? Have new non-lethal techniques been shown to be effective at deterring pinnipeds from predation that may be applicable to this interaction?

The Task Force[4] agreed by consensus to the following recommendation in response to Question 2:

The Task Force finds that the current hazing program does not appear to be effective at reducing predation in the area at this time. *As such, the Task Force recommends removing non-lethal hazing as a condition of the States' permit*. [emphasis added] Instead, allow the management agencies to modify the hazing plan as they deem necessary to enhance removal efforts and ask that any methods utilized continue to be monitored, evaluated and adapted to meet the overall goal of reducing predation to 1% or less.

Given these conclusions, and our own experiences with years of hazing CSLs at Bonneville Dam, Willamette Falls, and other locations, we are not proposing to conduct any non-lethal hazing activities in association with this Section 120 application.

C. *Sec. 120(d)(3)—the extent to which such pinnipeds are causing undue injury or impact to, or imbalance with, other species in the ecosystem, including fish populations;*

1. Status of the affected fish populations.

There is one Evolutionary Significant Unit (ESU) of salmon (Upper Willamette River Chinook) and one Distinct Population Segment (DPS) of steelhead (Upper Willamette River steelhead) in

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4 http://www.westcoast.fisheries.noaa.gov/publications/protected_species/marine_mammals/pinnipeds/sea_lion_removals/sec-120-tf-rpt-2010.pdf

the Willamette River Basin listed under the ESA[5] (NMFS 2016). Both runs were listed as threatened under the ESA in 1999 and both are subject to predation by CSL (and other pinnipeds) at Willamette Falls. The primary reason for listing these stocks was the effect of dams for hydropower and flood control, but tributary and estuarine habitat degradation, harvest, and hatcheries also contributed to the declines. Passage counts for steelhead and spring Chinook salmon over Willamette Falls are presented in Figures 6 and 7, respectively. Estimated adult returns over Willamette Falls for the four UWR steelhead tributary populations are given in the appendix (see Figure 1 in Appendix 2)

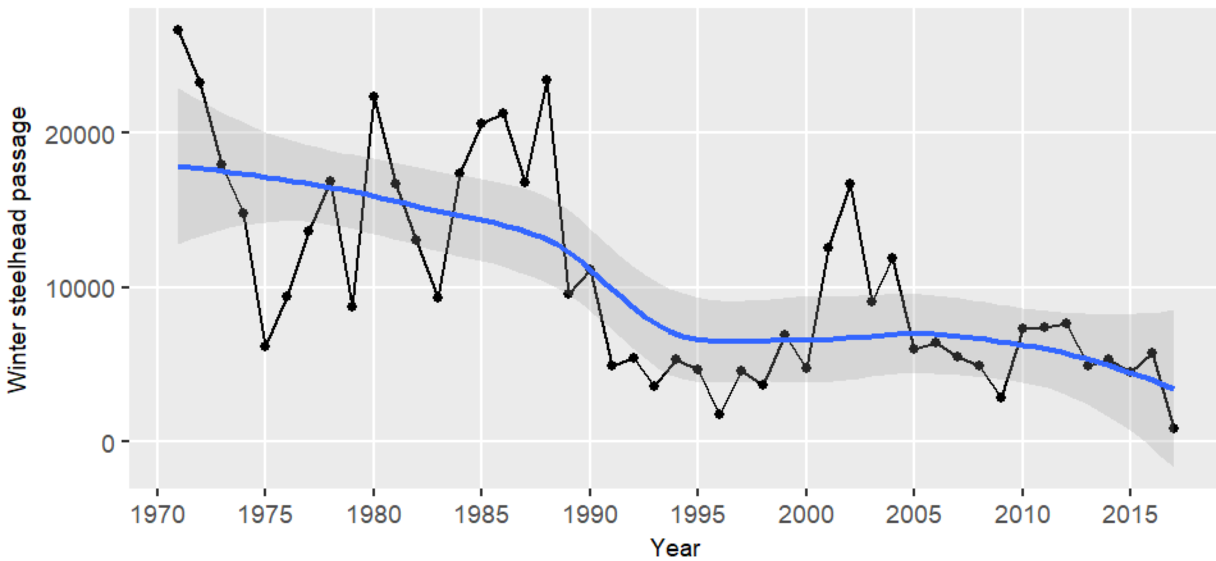

Figure 6. Total winter steelhead passage counts over Willamette Falls. Blue trend line equals loess fit to annual counts (span = 0.75); shaded area = 95% confidence interval. Pinniped predation occurs in the area immediately downstream of the fish counting station.

[5] The ESA defines a "species" to include any distinct population segment of any species of vertebrate fish or wildlife. For Pacific salmon, NOAA Fisheries considers an Evolutionarily Significant Unit, or "ESU," a "species" under the ESA. For Pacific steelhead, NOAA Fisheries has delineated Distinct Population Segments (DPSs) for consideration as "species" under the ESA.

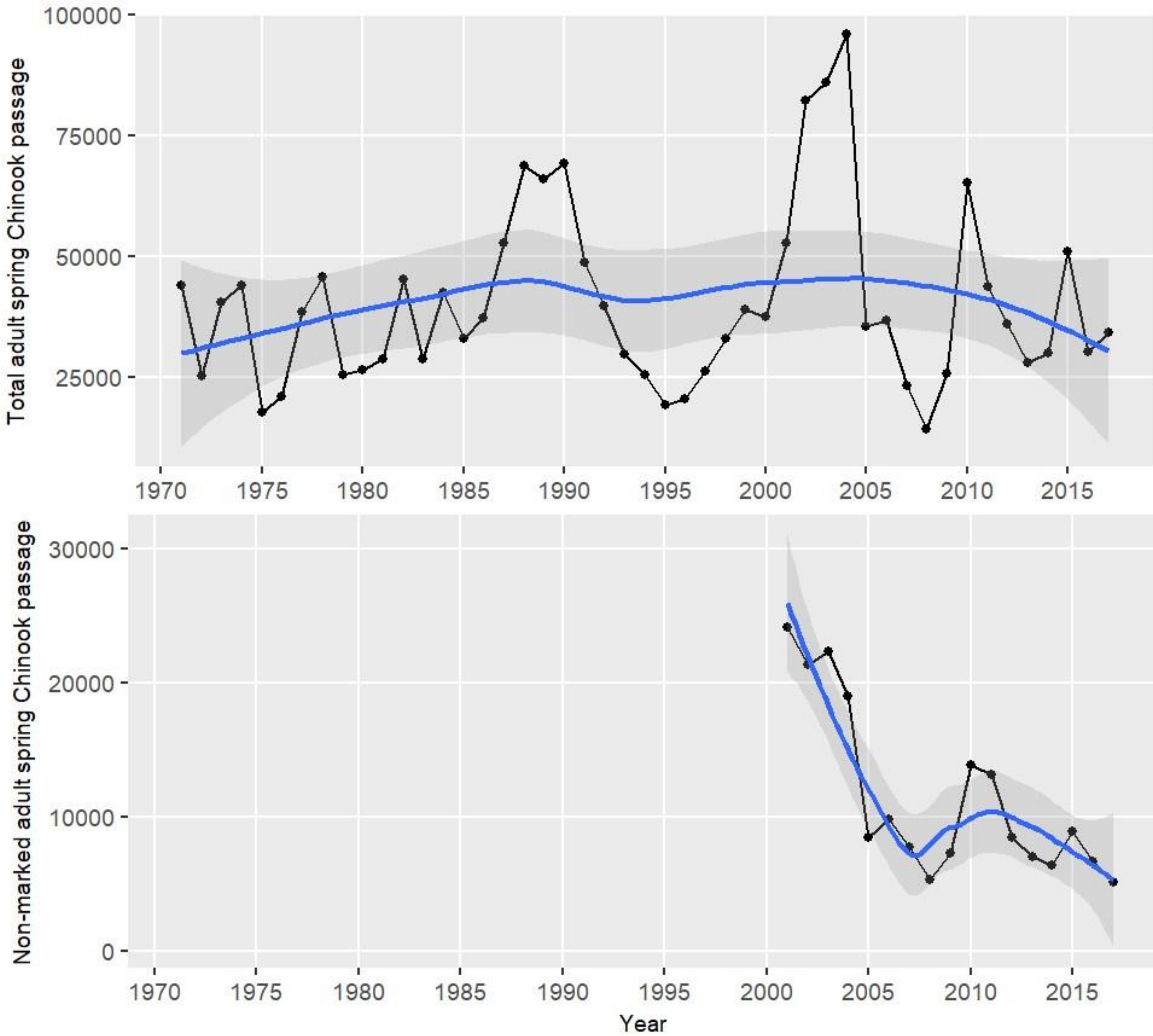

Figure 7. Total (upper panel) and naturally produced (lower panel) Upper Willamette River spring Chinook salmon passage counts over Willamette Falls. Blue trend line equals loess fit to annual counts (span = 0.75); shaded area = 95% confidence interval. Pinniped predation occurs in the area immediately downstream of the fish counting station.

To address the listing factors and promote recovery of UWR steelhead and spring Chinook, state and federal agencies, non-profit groups, and private landowners have taken a number of actions since 1999. Examples of these actions are outlined in detail in Section III C 4 of this application. The most recent status review for the UWR winter steelhead DPS and spring Chinook salmon ESU concluded that, with the exception of predation, other threats are stable or decreasing. However, the review concluded that both should continue to be classified as threatened under the Endangered Species Act (NMFS 2016).

The Upper Willamette River Conservation and Recovery Plan for Chinook salmon and Steelhead (ODFW and NMFS 2011) classified the UWR steelhead DPS as ranging from low to moderate risk of extinction and UWR spring Chinook ESU as ranging from low to very high risk of extinction

Both the 2016 status assessment and the 2011 recovery plan were completed before data were available to analyze the impact of sea lion predation at Willamette falls. However, the 2016 NMFS status assessment noted that pinniped predation on these stocks remained a concern and concluded that sea lion predation was increasing at an unprecedented rate. The assessment also noted that:

> "…*while there are management efforts to reduce pinniped predation in the vicinity of Bonneville Dam, this management effort is insufficient to reduce the severity of the threat, especially pinniped predation in the Columbia River estuary (river miles 1 to 145) and at Willamette Falls*"

2. Predation rates

While pinnipeds can consume small prey underwater they usually must surface to manipulate and consume larger prey such as an adult salmonids (Roffe and Mate 1984). Surface-feeding behavior can therefore be measured using statistical sampling methods (e.g., Lohr 1999) to estimate the total number of adult salmonids consumed by sea lions at a given place and time (see Wright et al. 2007, Wright et al. 2014, Madson et al. 2017 for details). We used this approach at Willamette Falls from 2014-2017 to estimate total salmonid predation which was further partitioned by run (i.e., summer/winter steelhead, marked/unmarked spring Chinook salmon) based on a combination of field observations, fish ladder window counts, and Monte Carlo methods. The results from those analyses are presented in Table 5. It should be noted that predation estimates only apply to the sampling frame and are therefore minimum estimates since we documented predation activity outside of the sampling frame during each study season. In addition, sampling frames varied by year so annual predation estimates are not directly comparable across years without further assumptions.

Table 5. Estimated salmonid predation by California sea lions at Willamette Falls, 2014-2017.

	Estimated predation				% of potential escapement			
Run*	2014	2015	2016	2017	2014	2015	2016	2017
wSTH	780	557	915	270	13%	11%	14%	25%
nmCH	496	899	650	399	7%	9%	9%	6%
sSTH	712	172	768	181	3%	4%	3%	8%**
mCH	1,703	4,149	2,252	1,824	7%	9%	9%	6%

*wSTH = winter steelhead; nmCH = spring Chinook salmon (not marked); sSTH = summer steelhead; mCH = spring Chinook salmon (marked)
**As of 8/15/2017

3. Impact to UWR steelhead

To evaluate the impact of predation on the population viability of UWR steelhead, ODFW conducted a 100-year population viability analysis (PVA; Appendix 2). The PVA was run under four different scenarios for each population (Table 6), where the assumptions under each scenario were held for all 100 years of the PVA simulation. In the scenario called “No Sea Lions” it was assumed that there is no additional mortality beyond incidental fishery mortality during the adult life stage. The scenario called “2015 Sea Lions” perpetuated the lowest predation mortality rate observed since 2014 and the scenario called “2017 Sea Lions” perpetuated the highest predation mortality rate observed since 2014. The results of the PVA indicated that sea lions had a large negative effect on the viability of winter steelhead in the three major populations (North and South Santiam and the Molalla) (Table 6). A similar analysis is being completed for UWR spring Chinook but is not yet available.

Table 6. Probabilities of quasi-extinction over a 100 year period in four populations of Willamette River winter steelhead under four different scenarios. Scenarios with sea lions assume that the predation mortality estimated during that year will continue indefinitely. The lowest predation rate was observed in 2015 and the highest predation rate was observed in 2017.

	Population			
Scenario	N. Santiam	S. Santiam	Calapooia	Molalla
No Sea Lions	0.015	0.048	0.993	0.000
2015 Sea Lions	0.079	0.158	0.998	0.001
Average Sea Lions	0.274	0.335	0.999	0.021
2017 Sea Lions	0.644	0.599	0.999	0.209

4. Addressing predation as part of a comprehensive fish recovery strategy

It is important to note that nearly all other sources of in-river mortality for ESA-listed salmonids in the Willamette River are being actively managed (e.g., through harvest reductions; changes in Willamette Basin Project operations, configuration, and management of the basin water supply; habitat restoration; and hatchery reform). Fishery actions are guided by Fisheries Management and Evaluation Plans (FMEPs). Recovery actions are guided by the Willamette River Biological Opinion (NOAA 2008) and The Upper Willamette River Conservation and Recovery Plan for Chinook salmon and Steelhead (ODFW and NMFS 2011). The Biological Opinion outlines Reasonable and Prudent Alternatives (RPA’s) and timelines for the action agencies to address the impact of hydro/flood control, hatchery, and associated habitat limiting factors and threats. The Recovery Plan incorporates all the RPA measures and includes additional actions that are outside the scope of the Biological Opinion.

Actions implemented under the guidance of these two documents include but are not limited to the following:

Harvest Reductions. Since UWR winter steelhead and spring Chinook salmon were ESA listed, harvest management has undergone substantial reforms to reduce freshwater fishery impacts -

those occurring in the mainstem Columbia River and the Willamette River - on these populations. Fishery impacts on wild UWR spring Chinook salmon have been reduced by more than 75% compared to levels before ESA listing. The focus is now on conservation of UWR wild populations and secondarily on providing harvest opportunity where possible directed at harvestable hatchery stocks. Principles of weak stock management are now the prevailing paradigm and wild (natural-origin) UWR salmon and steelhead are no longer targets of directed fisheries. Freshwater fisheries are managed based on the needs of natural-origin stocks and managers also annually assess total harvest mortality across all fisheries (ocean and freshwater).

UWR steelhead—There is no directed harvest of adult UWR winter steelhead. The State of Oregon developed a Fisheries Management and Evaluation Plan (FMEP) under NMFS' 4(d) Rule for the management of steelhead fisheries in the Willamette River. This management plan specifies the harvest regime for steelhead and has been approved by NMFS under the ESA. Incidental mortality of UWR steelhead in the main stem Columbia and Willamette River sport fisheries is estimated at 0-3 percent annually (ODFW and NMFS 2011) whereas UWR fisheries average 1.2% (ODFW 2001). To protect young winter steelhead (which often cannot be distinguished from rainbow trout), all trout fisheries in the four populations of the DPS are catch and release for wild trout (which includes unidentified juvenile steelhead). Prior to ESA listing, harvest of UWR wild winter steelhead was typically greater than 20% (ODFW 2001). In the 1970s, retention of steelhead in non-tribal commercial fisheries in the Lower Columbia River was prohibited and tribal fisheries above Bonneville Dam do not impact UWR steelhead (NWFSC 2015).

UWR spring Chinook salmon—The State of Oregon developed a Fisheries Management and Evaluation Plan (FMEP) under NMFS' 4(d) Rule for the management of spring Chinook salmon fisheries in the lower Columbia River and Willamette River. This management plan specifies the harvest regime for spring Chinook salmon and has been approved by NMFS under the ESA. Total mortality of naturally-produced UWR spring Chinook that are incidentally encountered in freshwater commercial and sport fisheries are capped at ≤15%. However, annual mortality rates since implementation of the mark-selective hatchery-only harvest strategies in these fisheries have more typically been in the range of 8-12%. This selective fishing regime has resulted in an approximate 75% reduction in average fishing mortality compared to previous years (1981-1997; ODFW 2001).

The NMFS evaluated ODFW's FMEPs for UWR spring Chinook and winter steelhead and determined the FMEPs adequately addressed all of the criteria specified in limit number 4 of the 4(d) Rule (ODFW 2016) resulting in a no jeopardy conclusion. Additionally, the most recent status review for UWR spring Chinook and winter steelhead (NMFS 2016) concluded that harvest-related impacts on natural-origin spring-run Chinook salmon and winter steelhead remain low on all populations in the ESU and DPS.

Willamette Basin Project (WBP). Mitigation for dam construction under the WBP was initially focused on producing hatchery fish to replace lost natural fish production, but in recent years mitigation efforts have also focused on operations, configuration, and management of the basin water supply to improve survival of natural origin salmon and steelhead. Examples include:

- Upstream adult collection facilities have been built in the North and South Santiam Rivers and at Cougar dam in the McKenzie River.
- An adult passage facility is currently under construction at Fall Creek Dam.
- Design planning is underway for a juvenile downstream passage collector at Cougar Dam.
- A temperature control tower was constructed in the Cougar reservoir to improve downstream temperatures.
- An improvement to the Foster downstream passage fish weir in the South Santiam River is about to be implemented in 2018.
- US Army Corps is currently in the early stages of design for temperature control and downstream passage at Detroit Dam on the North Santiam River.

These efforts are currently guided by the Reasonable and Prudent Alternatives (RPAs) outlined in the Willamette River biological opinion (NMFS 2008). The RPAs address the impacts of the WBP as outlined in recovery plans for winter steelhead and spring Chinook (ODFW and NMFS 2011).

Habitat Restoration. Since the time of ESA listing there has been considerable investment in restoring habitat to improve degraded habitat conditions and restore fish passage throughout the basin. Efforts are being undertaken by both state and federal agencies and non-governmental organizations. Specific projects and planning efforts are too numerous to mention here though some key measures implemented to address the habitat limiting factors in the UWR Recovery Plan (ODFW and NMFS 2011) include:

- Willamette Special Investment Partnership—OWEB's Willamette Special Investment Partnership was initiated in 2008 and focuses on funding restoration efforts in the mainstem Willamette and model watersheds (Calapooia, Long Tom, Luckiamute, Marys River, Middle Fork Willamette, North Santiam, and South Santiam). Since 2008, OWEB has invested approximately $6.08 million in main stem Willamette restoration and $3.16 million in the model watershed program.

- Willamette River Initiative—Since 2007, Meyer Memorial Trust has invested over $11.4 million in the Willamette River Initiative (~$4.3 million in the mainstem; ~$5 million in the model watersheds; ~$2 million for basin-wide impact – monitoring, demonstration projects, tools and resource development).

- Willamette Wildlife Mitigation Program—In 2010, the State of Oregon and Bonneville Power Administration (BPA) entered into a fifteen year agreement to permanently settle wildlife mitigation responsibilities for the federal Willamette River Basin Flood Control and Hydroelectric Project in the Willamette subbasin. The Agreement provides funding for habitat protection in the Willamette Basin, and requires that at least 10% of the funding protects habitat that provide dual benefits (benefit wildlife and ESA-listed anadromous fish). Since the Agreement was signed in 2010, just over 7,000 acres of wildlife habitat have been permanently protected in the Willamette Basin. This includes an investment of approximately $37 million by BPA, as well as leveraging over $11 million in cost share from the Program partners. Over 2,600 acres of those protected were designated as 'dual benefit' projects that will benefit both wildlife and ESA-listed anadromous fish.

The 2016 status review for UWR spring Chinook and steelhead (NMFS 2016) found that a number of restoration and protection actions have been implemented in freshwater and estuary habitat throughout the range of UWR salmon and steelhead. However, at this time the information is not available to document the effects of these actions on habitat quality, quantity, and function. As a result, NMFS concluded that the risk to the species' persistence because of habitat destruction or modification had not changed since the last status review.

Hatchery reform—ODFW discontinued the winter steelhead hatchery program in the Willamette basin in the late 1990's. Similarly, hatchery coho and fall Chinook releases above Willamette Falls have been eliminated because these species were not native or could affect the native stocks. The spring Chinook, summer steelhead, and catchable trout programs in the basin have been significantly reformed to assure that they either assist in the recovery of natural populations or mitigation hatchery programs do not impede progress towards recovery. Specific measures include (but are not limited to):

Broodstock

- Managed summer steelhead brood stock to further separate temporal overlap of spawning winter and summer steelhead.

Release Strategies

- Reduced spring Chinook production at McKenzie hatchery to reduce straying of hatchery fish to the spawning grounds
- Ended fall releases of Chinook salmon from the McKenzie Hatchery
- Reprogrammed Chinook salmon releases into the Coast Fork Willamette River, using Willamette stock instead of McKenzie stock to reduce straying back into the McKenzie.
- Curtailed juvenile releases of hatchery-origin Chinook salmon and steelhead trout into wild fish sanctuary waters (above Leaburg, Foster, and Minto Dams).
- Eliminated most releases of catchable trout in running waters where fisheries might incidentally catch spring Chinook smolts.
- Released only triploid catchable trout to reduce potential for reproductive interactions with native conspecifics.
- Released only smolt-sized summer steelhead to minimize competition with native salmonids.

Reduction of hatchery fish on spawning grounds

- Released only non-fin clipped Chinook salmon and steelhead trout above Minto, Foster, and Fall Creek dams.
- Instituted removal of surplus hatchery Chinook at Leaburg Hatchery to reduce straying of hatchery fish to the spawning grounds.
- Increased capture efficiency at McKenzie Hatchery trap to increase removal of hatchery-origin Chinook salmon.

- Constructed acclimation site in the Molalla River to improve homing of hatchery origin spring Chinook.
- Reduced recycling of summer steelhead ("one and done" on the N. Santiam River).
- Fin-clipped summer steelhead are not passed above any of the major UWR project dams.

Operation of each hatchery program is subject to NMFS review. In 2000, NMFS issued a Biological Opinion with a no jeopardy determination for all the hatchery programs in the UWR that included significant hatchery reforms. These reforms were implemented by the agencies to reduce impacts of the programs on wild populations of spring Chinook and winter steelhead. NMFS consulted again on all of the hatchery programs as part of the WBP (including operation of the 13 federal dams) and issued an RPA that included additional hatchery reforms. These actions have also been implemented by the agencies (see partial list above). New HGMPs were submitted to NMFS for another ESA consultation to allow natural-origin Chinook salmon to be taken for broodstock purposes (integrate hatchery stock with local, wild population). The hatchery programs for summer steelhead and rainbow trout are currently authorized by the 2008 Willamette River Biological Opinion. The agencies are updating the HGMPs for steelhead and rainbow trout and planning on submitting the HGMPs to NMFS for another consultation.

The above investments are being made to improve survival of the ESA-listed salmon and steelhead in the Willamette River basin and will continue as the RPA's documented in the Biological Opinion and tasks identified in comprehensive recovery plans are implemented. Despite all of these efforts, UWR steelhead are now at high risk of extinction. Both the abundance of CSLs and duration of their occurrence at Willamette Falls is increasing and predation rates represent a significant threat to the persistence of UWR spring Chinook salmon and winter steelhead which must be managed to allow longer term recovery actions time to take effect. All threats to recovery must be appropriately minimized, including CSL predation on salmon and steelhead at Willamette Falls.

D. Sec. 120(d)(4)—the extent to which such pinnipeds are exhibiting behavior that presents an ongoing threat to public safety.

California sea lions often exhibit bold and aggressive behaviors that include stealing hooked fish while they are being landed, even to the point of taking the fish from a landing net or the hands of an angler bringing the fish into the boat. There have been reports of anglers being bitten by sea lions in this situation as well as anglers being pulled overboard while holding onto a landing net that was grabbed by a sea lion[6]. Many sport angling vessels are small and could be capsized by these types of actions by sea lions taking hooked or netted fish from anglers close to the boat.

[6] http://www.oregonlive.com/portland/index.ssf/2011/05/sea_lion_yanks_a_willamette_ri.html

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APPENDIX 1. Excerpted review of pinniped deterrence methods from Scordino (2010).

PINNIPED DETERRENCE

A variety of measures have been considered, tested and/or implemented to deter or remove pinnipeds from areas where their presence 1) creates conflicts with other resources, 2) results in interactions with human activities (including fishing), or 3) threatens human safety and/or damages property. The following is a description and evaluation of the effectiveness of measures that have been attempted by state and federal fishery/wildlife officials to control pinnipeds in several problem situations (e.g., California sea lions killing salmonids at the Ballard Locks and Bonneville Dam), by fishermen to protect their catch and gear from pinnipeds, and by others to protect public safety or property. Guidelines for non-lethal measures that the public may use to deter pinnipeds as authorized under Section 101(a) of the MMPA can be found at the NMFS Northwest and Southwest Regional Office web-sites.

Firecrackers

Underwater firecrackers (called "seal bombs") are pyrotechnic devices that have been used to deter pinnipeds and disperse fish in a number of situations. Firecrackers used by state and federal wildlife managers were trade named “Seal Control Devices” that are manufactured in the U.S. and regulated by the U.S. Department of Transportation (49 CFR Subtitle B). The Seal Control Devices, which were commercially available for use as wildlife deterrents in agriculture and fishing applications, consisted of a spiral-wound cardboard tube containing 36 grains of potassium perchlorate and pyro-aluminum flash powder with an 8-second waterproof fuse and were weighted with sand so as to sink and explode underwater. They produced light and sound pressures on the order of 190 dB re 1 :Pa at one meter (Aubrey and Thomas 1984). Most of the sound energy was focused below one kHz which is below the range of maximum hearing sensitivity for sea lions.

Firecrackers were used successfully in 1986 to reduce sea lion predation on steelhead at the Ballard Locks. However, in subsequent years firecrackers became relatively ineffective on several sea lions that habituated to preying on steelhead at the Locks (Pfeifer et al. 1989). Although these sea lions were initially frightened by the firecrackers, they soon began to either return in a few hours or resumed preying on steelhead in a different area. Some sea lions, which had been observed over several seasons, appeared to have learned to ignore or tolerate the noise. They also appeared to learn to evade close exposure to firecrackers by diving and surfacing in unpredictable patterns (Pfeifer et al. 1989). Similar tolerance of firecrackers has been observed in fisheries interaction situations with harbor seals (Geiger and Jeffries 1986). Use of firecrackers to deter California sea lions at Bonneville Dam also have had limited effectiveness in keeping sea lions away from salmon forage areas near the dam (Brown et al. 2007).

No visible injuries to sea lions from firecrackers were observed during their use at the Ballard Locks (NMFS and WDFW 1985). Sea lions that were exposed to repeated use of firecrackers at the Locks from 1986 to 1988 were observed in subsequent years and showed no ill effects from the exposure. These same sea lions continued to react to noise stimuli indicating they had not been deafened by their exposure to firecrackers.

The advantage of firecracker use as a deterrence measure was that they were small, easily transported, inexpensive, and caused short-duration startle response in pinnipeds without harm if used properly. The disadvantage was that the deterrence effects were short-term and lost effectiveness when used repeatedly on the same pinnipeds.

Cracker Shells

Cracker shells are pyrotechnic devices discharged from a 12 gauge shotgun. The shells contain a flash explosive charge (same as a firecracker) that is designed to explode in air or on the surface of the water at a distance of 75 to 100 meters from the point of discharge. The impulsive noise from the shotgun firing is comparable to firing a regular round of ammunition, and the noise from the cracker shell explosion is similar to a firecracker. Noise from the cracker shell explosion is intended to startle the target animal and cause it to flee. There is no injury to the pinnipeds involved since the explosion is in the air or on the water's surface.

Cracker shells were used to deter California sea lions at Bonneville Dam with limited effectiveness in keeping sea lions away from salmon forage areas near the dam (Brown et al. 2007). Cracker shells also have been used in fishery interaction situations with harbor seals with limited effectiveness because the seals learned to avoid or ignore the noise (Beach et al. 1985).

The advantages and disadvantages of cracker shells were similar to firecrackers. They were favored over firecrackers when longer distance dispatch was necessary. However, their use was restricted or precluded in some areas because they required the use of a firearm.

Aerial Pyrotechnics

Aerial pyrotechnics (screamer rockets, poppers, banger rockets, bottle rockets) have been used to scare birds away from crops, to scare pinnipeds off docks, and to deter birds and sea lions at Bonneville Dam. The units were ignited using a hand held launcher (similar to a .22 short caliber starter pistol) and flew through the air, emitting a loud whistling sound (screamers) that ended with “bang” similar to a firecracker. Noise from screamer and banger rockets was less intense than cracker shells but still was intended to startle the target pinniped and cause it to flee. The units were used at Bonneville Dam to reduce avian predation on juvenile salmonids, and their use was extended to keep sea lions away from the fish ladder at Bonneville (NMFS 2008).

Acoustic Deterrents

Acoustic devices were developed in the 1980s to produce underwater noises at specific frequencies and with sufficient power to deter pinnipeds. Acoustic harassment devices (AHDs) were designed to produce high amplitude, pulsed but irregular "white noise" underwater in the 12 to 17 kHz range that is intended to cause physical discomfort and to irritate pinnipeds, thereby repelling them from the area of the sound. The output of AHDs is designed to vary randomly to reduce habituation. AHDs produce bursts of short, upswept tones at 160dB to 185dB.

One of the initial AHDs called a "Sealchaser" was developed by Oregon State University specifically for repelling pinnipeds in fishery conflict and other situations where there was a need to non-lethally remove pinnipeds (Mate et al. 1987). Initial testing of the Sealchaser with harbor seals indicated it could be effective in repelling seals from certain areas (Mate and Harvey 1987). A description of the Sealchaser and field tests is presented in a workshop report on "Acoustic

Deterrents in Marine Mammal/Fishery Conflicts" (Mate and Harvey 1987). Norberg and Bain (1994) measured the output of the Sealchaser and found that it produced source sound pressure levels of 188 dBRMS re 1 :Pa at one meter. The individual tones lasted approximately 0.1 seconds, and swept up in frequency from about 11.5 kHz to 15 kHz while increasing gradually in intensity. The bursts lasted four to five seconds, and consisted of approximately 20 to 25 tones.

AHDs were initially effective in some situations, but their effectiveness diminished in most situations apparently as pinnipeds learned to tolerate the noise. An AHD was used to attempt to control sea lion predation at the Ballard Locks, but was found to be ineffective (NMFS and WDFW 1995). Geiger and Jeffries (1986) reported that the use of an AHD on commercial fishing nets resulted in the devices appearing to act as a "dinner bell" attracting pinnipeds to the fishing gear because fishermen would turn the devices on when they had fish in their nets. The principal problem encountered with AHDs was that pinnipeds appeared to “learn” to tolerate the noise.

Sound pressures from these AHDs were probably not great enough to cause sufficient pain to overcome the ability of pinnipeds to learn that the negative stimulus could be tolerated.

Due to the inconsistent effectiveness of the AHDs, more powerful acoustic devices were created by the Airmar Corporation and tested at the Ballard Locks. These more powerful devices called “acoustic deterrent devices” (ADDs) were designed to cause pain to pinnipeds (rather than be just a physical discomfort or irritation as caused by AHDs). [Note: The term ‘ADD’ used herein should not be confused with pingers that also have been called ‘ADDs.’ Pingers are much lower dB acoustic devices used on nets to alert marine mammals of the nets presence.] The more powerful ADDs had omni-directional and unidirectional arrays which produced periodic sound emissions at higher decibel levels than the AHDs. The omni-directional ADDs produced periodic sound emissions at a frequency centered at 10 kHz with source levels that were measured to be between 190-196 dBRMS re 1 :Pa at one meter (Norberg and Bain 1994). Sound pressure levels produced by the directional ADD array were designed to be at or above the 200-220 dB estimated pain threshold for California sea lions (Aubrey and Thomas 1984). However, because of spreading losses on the order of 20 dB re 1 :Pa for each ten fold increase in distance, sea lions would not be exposed to sound pressures of this intensity unless they approach within about three meters of an operating directional transducer.

An “acoustic barrier” was created at the Ballard Locks in 1994 by placing arrays of the directional and omni-directional ADDs in the area below the spillway dam to create an ensonified zone (NMFS 1996). The array cycled through four transducers in a period of 17-17.6 seconds.

Each transducer fired individually in sequence during a cycle and produced a chirp lasting 2.3-2.5 seconds. Each chirp was composed of about 60 pulses lasting from 0.5-2.5 milliseconds each. A pause, lasting about two seconds occurred between chirps as the transmitter signal advanced from one transducer to the next. The directional ADD array produced sound pressures of about 206 dBRMS re 1 :Pa at one meter with a duration of approximately one millisecond, with the frequency centering at 15 kHz rather than 10 kHz (Norberg and Bain 1994). The “ensonified zone” created near the dam by the omni-directional arrays had sound pressures of approximately

170 dBRMS re 1 :Pa. These sound pressures were significantly decreased in the presence of turbulence caused by spill over the dam (Norberg and Bain 1994). Measured sound levels at distances greater than one meter ranged from 185.6 dBRMS for the directional array at 10 meters down to 139.7 dBRMS for the omni-directional array at 1000 meters (Norberg and Bain 1994). The array signal levels declined by about 17.8 dB for each 10-fold increase in distance.

Although sound pressure levels on the order of 200-220 dBRMS re 1 :Pa (for a constant tone of more than one second) could present some potential for causing temporary or permanent hearing loss for sea lions, field measurements showed that the duration of a pulse in the directional array was approximately one millisecond. In addition, because of spreading losses and boundary effects (i.e., reflection from surface and bottom, and absorption by entrained air), the area where sound pressures of this magnitude would be encountered by sea lions was quite small (within three meters of transducer). It was unlikely that sea lions would be in the immediate vicinity of an operating transducer for sufficient time to sustain permanent hearing damage. Subsequent observations of sea lions that had been exposed to the ADD array (i.e., entered the ensonified zone at the Ballard Locks) indicated these sea lions had not been deafened as they still reacted to noise stimuli.

In regard to effects on fish, AHD tests conducted by Mate et al. (1987) indicated that sound pressure levels of 185 dB/:Pa at one meter and frequency ranges from 8-12 kHz within an enclosed tank had no effect on adult salmonids or spawn viability. Frequencies above one kHz were beyond the normal "hearing" range of the fish.

The ADDs appeared to be effective in deterring new sea lions from the Ballard Locks area, but had less effect on California sea lions that repeatedly foraged at this site (NMFS 1996). However, even the “repeat” sea lions demonstrated altered behavior in the area of the ADDs. The “repeat” sea lions approaching the ADD array at the Ballard Locks did not frequently enter the ensonified area adjacent to the fish ladder, and on the few occasions when they did, they were there for very short periods of time. Their foraging behavior in the zone also was altered with more time at the surface and a tendency to stay in areas of turbulence where the ADD signal would have been reduced. The propagation of the signal from the acoustic devices was strongly influenced by turbulence and entrained air caused by water spilling over the dam. Air bubbles in the water column absorb the acoustic signal and sound levels decreased as spill increased (Norberg and Bain 1994).

ADDs also were used at Bonneville Dam. Directional transducers were placed on the bottom at the entrances to the fish ladders during the spring Chinook run. Observers did not report any obvious effects to the California sea lions foraging in the area (Tackley et al. 2008b).

Overall, although acoustic devices (AHDs and ADDs) had been successfully used to deter pinnipeds in some areas, there was concern that over time (perhaps months for harbor seals, days for California sea lions) pinnipeds would become tolerant of the sound and ignore it or change their behavior to limit the acoustic noise effects. Advantages were they could be effective for short-term, did not affect fish, and were easily controlled. Disadvantages were they were expensive and sometimes large (transmitter and batteries), and the transducers needed to be placed near the target animals away of turbulence. Some studies have indicated that acoustic devices placed in open marine areas (e.g., at salmon net pens) can affect harbor porpoise distribution and movements (Olesiuk et al. 2002).

Pulsed Power

Pulsed power is an electrical power (arc gap) discharge system that generates an electrical spark that creates a concussive pressure wave that turns into a sound wave. An arc-gap transducer to generate underwater shock waves was first tested on pinnipeds by Shaughnessy et al. (1981) to deter Cape fur seals from fishing nets and appeared effective at close range (2–10 m) but was ineffective at greater distances. An arc-gap system initially designed to remove fouling organisms from boat hulls was field tested on California sea lions in 1995 and had potential as a deterrent; however, the unit was large and its weight of over 136 kilograms made it infeasible for use on fishing boats. In 1997, NMFS awarded a Saltonstall-Kennedy grant to PSMFC to develop a practical pulsed power system that could be used on charter fishing boats. A prototype pulsed power device (PPD) was built by Pulsed Power Technology Inc. in 1998 for testing in open water to obtain actual signal output from the device and develop safe protocols for testing the device on California sea lions involved in fishery interactions.

The prototype PPD was an advancement of the arc-gap transducer concept (NMFS 1999b). As with the arc-gap transducer, the PPD pulsed electrical power discharge system was a compressed wave (shock-wave) generator that also produced an acoustical component. The primary difference between the PPD system and the arc-gap transducer used by Shaughnessy et al. (1981) was the stored energy available to create the arc. The PPD was capable of storing from one to three kilojoules (kJ) of energy as compared with 520 joules (0.52 kJ) in the device used by Shaughnessy et al. (1981). In both systems, energy was transferred from a charged capacitor bank into an underwater "arc-gap." The electrical discharge from PPD created a dense, highly ionized plasma (ionized gas) channel across the gap in the underwater projector unit. The plasma channel was created within a few microseconds (:sec), and a compression wave was produced by the expansion of the bubble surrounding the plasma channel. Within a millisecond, the plasma channel dissipated and the bubble collapsed. The two events (expansion and collapse of the bubble) produced a compression wave followed by an acoustic wave.

The prototype PPD generator consisted of two parts, a deck transmitter unit and an underwater transducer unit (NMFS 1999b). The deck unit, consisting of a rectangular box with a cable storage reel, was 71 centimeters (cm) high, 61 cm long, and 46 cm deep. It weighed 27 kilograms (kg) without cables. The underwater unit was 20 cm in diameter, and 224 cm long, with a lifting eye hook. With a stainless steel housing, the underwater unit weighed 98 kg. The pulse rate and output energy level could be adjusted by the operator either manually or cycled automatically. The pulse signal was generated by discharging an electric arc between two electrodes immersed in the water column. The transducer unit was capable of a minimum energy output of approximately one kJ and a maximum output of three kJ; however, consistent firing was more difficult to obtain at the one kJ setting and required a special setting of the output spark gap electrodes. Although the PPD was capable of outputting three kJ of energy, NMFS-SWR did not want the device used at this energy level due to potential effects on other wildlife. Field measurements of the PPD indicated that the sound pressure levels decreased to 180 dBRMS re 1 :Pa at a distance of 200 meters for a source energy of 1.34 kJ and at a distance of 262 meters for a source energy of 1.8 kJ. Source sound pressure levels on the order of 240 dBpeak re 1 :Pa at one meter were calculated based on received levels of 209 dBpeak at 44 meters for output of 1.8 kJ. The pulse duration was less than 500 microseconds (:s).

The prototype PPD was tested on California sea lions in captivity (Finneman et al. 2003) and found to be effective in safely deterring sea lions without causing permanent hearing damage to the involved sea lions.

The field effectiveness of the prototype PPD has yet to be evaluated under a rigorous monitoring program. There was uncertainty on whether it would be feasible for use on fishing vessels to deter sea lions because of the size of the device (transducer was over two meters long and weighed 98 kg.).

Taste Aversion

Taste aversion is a form of aversive conditioning that involves putting an emetic agent (e.g., lithium chloride) into a prey species to induce vomiting when the prey is consumed. This technique has been used on coyotes and was successfully tested on a prey specific basis with captive California sea lions (Kuljis 1986). Kuljis (1986) conditioned captive sea lions to avoid one of three prey species without affecting the sea lions' desire to eat the other two species using lithium chloride treated fish. Taste aversion using lithium chloride was attempted on California sea lions at the Ballard Locks, but the effort was not successful (NMFS and WDFW 1995). A variation on this method, which has not been tested, would be to dart (inject) an emetic such as apomorphine or ethylestridiol directly into a pinniped when it consumes a fish or enters an area. The same theory applies, if the pinniped associates becoming sick with entering an area or consuming fish in that area, it would develop an aversion.

The potential advantage of taste aversion is conditioning pinnipeds to avoid specific fish (e.g., salmon). A disadvantage is that the treatment must be applied at least twice to achieve results.

NMFS found that taste aversion is not a feasible deterrence approach in most cases due to the difficulty in repeated field application and uncertain results along with the possibility that treated fish might be lost and consumed by other wildlife (NMFS and WDFW 1995).

Predator Sounds

The underwater broadcast of killer whale sounds has been attempted with marine mammals to move them away from an area. The effectiveness of predator vocalizations to frighten sea lions has not been consistent (NMFS and WDFW 1995). Pinnipeds sometimes have shown immediate avoidance responses to the projection of killer whale sound recordings, but generally they have habituated quickly. In one study, sea lions were actually attracted to a researcher's broadcast of predator vocalizations in the Baja California area. NMFS found that this approach was not practical for pinniped deterrence and does not warrant further consideration (NMFS and WDFW 1995).

Predator Models

Placement of predator models (such as fiberglass models of killer whales or great white sharks) to deter pinnipeds has been suggested, but has not been used on the west coast due to its likely ineffectiveness. There were media reports on the effective use of a killer whale model in repelling seals from net-pens in Scotland; however, use of the same predator model at net-pens in Maine had no effect in repelling harbor or gray seals (NMFS and WDFW 1995). NMFS dismissed testing of a three-meter killer whale model (secured by a local radio station) at the Ballard Locks because it was highly unlikely that sea lions would react to the model predator and NMFS did not want to be involved in a "media show." Past field observations of pinnipeds in proximity to natural predators, and the problems and limitations with maneuvering predator models led NMFS to conclude that the predator model approach was not practical and does not warrant further consideration (NMFS and WDFW 1995).

Chasing or Hazing

Boats have been used to attempt to scare or chase pinnipeds at the Ballard Locks, at Bonneville Dam, and in gillnet fisheries. This method was not totally effective as pinnipeds in many cases simply swam under the boat and resisted leaving the area. Aggressive boat maneuvering combined with use of underwater firecrackers was initially effective at the Ballard Locks, but became less effective as California sea lions learned to avoid the boat or temporarily move downstream and then immediately return to the Locks (Pfeifer et al. 1989). Fishermen have used their vessels to chase seals and sea lions from their operation, but such efforts were usually unsuccessful (Beach et al. 1985).

Rubber Projectiles

Shotgun-fired rubber buckshot and slugs designed to non-lethally repel bears have been used on California sea lions at Willamette Falls and at Bonneville Dam. Rubber-tipped arrows shot from a crossbow were used on California sea lions at the Ballard Locks. The discharge of rubber projectiles were intended to deliver a non-lethal impact causing potential bruising but not penetrating the skin. The rubber projectiles were directed at the exposed part of the target animal's body, avoiding the head and eyes, to achieve the deterrent effect.

During rubber-tipped arrow use at the Ballard Locks, California sea lions showed avoidance behavior after being hit while others did not. One sea lion that accounted for the majority of the steelhead kills entered the target zone 70 times and was hit six times (Pfeifer et al. 1989). This animal appeared to avoid the area near the shooter, but still preyed on steelhead.

At Willamette Falls, ODFW tested the use of rubber projectiles (rubber buckshot and batons) shot from a shotgun over a four day period. Four individually recognizable sea lions were shot with rubber buckshot and batons in 1986. The smaller and less commonly occurring sea lions immediately left the area when shot and did not return. Larger animals returned to the immediate area in less than 24 hours and were more wary on return, moving from area to area, surfacing in less predictable ways and spending more time underwater thus preventing dispatch of another rubber projectile (NMFS and ODFW 1997). In subsequent attempts by ODFW, the sea lions appeared to learn to avoid the fish ladder area where the shooter was located and foraged out of range near the falls (Boatner 2000). The use of paint balls dispatched from a CO2 pistol at Willamette Falls had effects similar to the other deterrents in that the struck sea lions would move from the immediate area but continued foraging (Boatner 2000).

At Bonneville Dam, shotgun dispatched rubber buckshot and batons were used on California sea lions in 2006 through 2008. Over 3,000 rubber buckshot/baton rounds were used from boats during the three years with limited effectiveness in deterring sea lions (Brown et al. 2008). The advantage of shotgun fired rubber projectiles was that they delivered a non-lethal blow concurrent with the noise of the shotgun blast. In most cases, they did cause an initial flight response by the targeted pinniped. Disadvantages were that they needed to be used in close proximity to the targeted pinniped and shooting was difficult because only a small portion of the pinniped typically showed for a only a short amount of time. Although most individual pinnipeds temporarily reacted when hit, they did not always leave the foraging area and in many instances immediately returned. Use of rubber projectiles also posed safety hazards to people in the immediate area due to potential ricochet, and thus could only be used in restricted areas.

Physical Barriers or Exclusion Devices
Where feasible, physical structures have been placed to exclude or prevent pinnipeds from accessing areas such as fish ladders. At Bonneville Dam, sea lion exclusion devices were installed at the entrance to each fish ladder to prevent sea lions from entering the fish ladder (Tackley et al. 2008a). The welded aluminum grate structures, consisting of a series of evenly spaced vertical bars, were installed in the eight fish ladder entrances just prior to the spring Chinook salmon migration each year. The bars provided sufficient spacing for migrating salmon to pass, but the spacing was too narrow for sea lions to easily enter. A similar grate structure was installed at the fish ladder entrance at Willamette Falls to prevent sea lions from entering the fish ladder (NMFS and ODFW 1997). Prior to installation of these structures, California sea lions were frequently entering the fish ladders at Bonneville Dam and Willamette Falls. At Bonneville Dam, one sea lion was still able to enter the fish ladder. Lack of access to the fish ladder did not deter sea lions from feeding on salmonids near the ladder entrance.

A physical barrier was tested at the Ballard Locks to prevent sea lion access to a prime forage area near the entrance to the fish ladder (sea lions were not entering the fish ladder, but foraged effectively on steelhead as they approached the ladder entrance). The experimental barrier at the Ballard Locks (a large-mesh net strung underwater) was ineffective because fish passage may have been hampered by the barrier and because sea lions quickly learned to effectively forage on steelhead at the face of the barrier (NMFS and WDFW 1995).

At the Dosewallips River, a barrier was placed across the river mouth to prevent harbor seals from entering a channel in the river where harbor seal presence was causing high fecal coliform counts in shellfish beds. The fence type barrier at the Dosewallips River was effective in excluding harbor seals from a haul-out site and resulted in lowered fecal coliform counts at the shellfish beds. Flood conditions subsequently washed out the fence and it was not replaced because fecal coliform levels did not exceed acceptable levels.

Railings and fences have been used to prevent sea lions from hauling out on docks and buoys in a number of areas. The barriers had to be designed to allow people access to docks from their boats while preventing access by pinnipeds.

At some salmon net-pen facilities, a larger mesh “predator” net has been installed outside the inner net pens as a barrier to prevent sea lions from biting salmon inside the pens. These predator nets have had mixed success because, unless the net is very taunt, sea lions can push the predator net against the inside net and still bite and damage salmon in the pen.

Electric Barrier

Electrical fields have been used in fresh water to create underwater barriers that limit fish movements (such as carp and lamprey in the Great Lakes), and in 2007 were tested as a potential pinniped deterrent. An electrical barrier functions by establishing an underwater graduated electric field of low-voltage DC between an anode and cathode placed up to several meters apart in the water. Forrest et al. (2009) found that an electrical barrier could be established that would repel seals and sea lions, without affecting the fish on which they were feeding. An electric gradient was tested in a tank on two captive harbor seals, and found to cause an avoidance response at voltage gradients and pulse width settings much less than typically required for freshwater fish (Forrest et al. 2009).

In April 2007, the electric voltage gradient was tested on harbor seals in the field on four days at the Puntledge River in Courtenay, B.C. This site was chosen because studies by Olesiuk et al. (2001) had documented harbor seals in the Puntledge River using the light-shadow boundary from the lights on the 5th Street Bridge to forage on out-migrating juvenile salmon. The Puntledge River at the 5th Street Bridge was considered to be an ideal location to field test deterring seals from feeding on juvenile salmon using an electrical gradient system because the system could be fixed on the river bottom, and the effects on harbor seals easily observed. Forrest et al. (2009) found that harbor seals avoided the electrical field and did not pass through the area when the system was on. Seals returned to their normal feeding behavior in the electrical array area shortly after the power was turned off and in subsequent days.

In August 2007, an experimental salmon gillnet with a built-in electrical gradient system was constructed to test the effectiveness of the electric barrier in reducing harbor seal predation on gillnet caught salmon in the Fraser River (Forrest et al. 2009). The net was divided into two 50 fathom sections: a control section receiving no treatment and a treated electric section. A portable 3.5 KW AC generator, attached to a DC Pulse Generator unit, located onboard the fishing vessel, supplied the electrical power to the system. Forrest et al. (2009) found that harbor seals appeared to be deterred from the electric section of the net. The total salmon catches and cumulative catch- per-unit-effort (CPUE) were substantially greater for the electric section of the net (1,108 salmon, 298.9 CPUE) as compared to the control section (272 salmon, 50.7 CPUE).

This technology has been proposed for testing at Bonneville Dam to deter California sea lions. Such testing, if conducted on a longer term basis (i.e., through the entire 3-4 month period that sea lions forage in the area) should provide data needed to adequately evaluate the field effectiveness of this technology. It also would be useful to have the concept tested for the entire period that juvenile salmon migrate out of the Puntledge River to determine if the application has continuing effectiveness or if the seals “learn” to forage either in the electrified zone or in adjacent or nearby areas. A measure of success for this technology in the Puntledge would be cessation of harbor seal predation at the site during the juvenile salmon out-migration period.

Capture and Removal
Capture and relocation efforts with California sea lions at the Ballard Locks indicated that transporting captured sea lions relatively short distances (from Ballard to the outer Washington coast) was not an effective approach because the sea lions quickly returned. Similar results occurred with California sea lions relocated from Bonneville Dam to the outer Oregon coast.

Longer distance relocation of California sea lions from Ballard to the southern California breeding area also resulted in sea lions returning. This costly and labor intensive long-distance relocation did provide a means of delaying sea lion return for at least 30 days, thereby providing a window of safe passage for migrating salmonids that season (NMFS and WDFW 1995). However, the disadvantage was that some of the "targeted" sea lions (those had been captured/removed previously and returned to forage at the Ballard Locks) could not be recaptured (NMFS 1996). A harbor seal also was captured and relocated a relatively short distance (Ballard Locks to Hood Canal), and the seal also soon returned to the problem area.

One of the California sea lions captured at the Ballard Locks was placed in temporary captivity and released after the steelhead run. Temporary holding was found to be ineffective in the long-term because this sea lion returned the following season and could not be recaptured before it had preyed on salmonids (NMFS 1996).

California sea lions from the Ballard Locks and Bonneville Dam also have been captured and placed in captivity permanently as a means to eliminate the conflicts they caused. Although permanent captivity does eliminate the "problem" sea lions without having to kill them, the method is costly, labor intensive, and limited by the availability and interests of display facilities that are willing to keep the sea lions permanently.

Population Control
An overall reduction of the pinniped populations has been speculated as a means to reduce coastwide pinniped interactions and conflicts. However, because many of the conflict situations involve individual pinnipeds that are repeatedly involved in interactions and problem situations, it is unclear how a population control program would be effective unless these individual animals were specifically targeted as part of the population reduction effort. Pinniped population reduction programs such as controlling grey seals in Scotland were not successful or did not have the rigorous monitoring necessary to scientifically document the effects (Bonner 1982).

There have been public suggestions to reduce the numbers of California sea lions through birth control. Reducing the number of sea lions through this approach though would not reduce current pinniped conflicts because it would only affect pup production and not the current number of sea lions that cause fishery interactions or other conflicts. Over the long term, such an approach would not be effective unless "new" sea lions did not learn the problem behaviors.

Reducing pinniped numbers as a means to control conflict situations is unlikely to be successful. NMFS (1999a) determined that population control was not a feasible approach to resolving pinniped conflicts, but that targeted lethal removal of the problem animals was a reasonable approach and the MMPA should be amended to allow such removal by state and federal wildlife officials.

Selective Lethal Removal of "Problem Animals"

NMFS (1999a) determined that lethally removing the individual "problem" pinnipeds may be the only efficient and cost-effective method to reduce or eliminate pinniped conflicts in many situations. NMFS (1999a) found that non-lethal methods have limited effectiveness and that lethal removal of the individual offending pinnipeds was warranted when such pinnipeds from healthy, robust populations were having negative effects on ESA-listed salmonid populations.

Deterrence Summary

In most cases, non-lethal deterrence measures were found to have limited or short-term effectiveness because pinnipeds appeared to learn to avoid or ignore the measure applied. The use of noise or other stimuli that cause a startle and flight response in pinnipeds were found to cause initial fright reactions and short-term avoidance, but the measures were eventually ignored or avoided by pinnipeds that had prior exposure. During many years of attempting to deter California sea lions from foraging on steelhead at the Ballard Locks (Scordino and Pfeifer 1993), NMFS and WDFW found that non-lethal deterrence measures had to inflict physical pain to the pinniped in order to effectively deter the pinniped beyond the initial startle response especially when the pinniped had previously foraged on salmonids at the site (NMFS 1996). Otherwise, the only effective measure was removal of the pinniped. ODFW and WDFW had the same results in attempting to deter California sea lions from Bonneville Dam (Brown et al. 2008).

APPENDIX 2. Population viability of Willamette River winter steelhead.

This document describes methods used to assess the effects of sea lions at Willamette Falls on the viability of four populations of wild winter steelhead. Several data sets were compiled, manipulated, statistically modeled, and ultimately used to project population dynamics through time. An accompanying webpage provides all the data and MATLAB computer code to replicate results: http://people.oregonstate.edu/~falcym/WillametteSteelhead.html

Contents

PVA Results

The results of the PVA indicate that sea lions have a large negative effect on the viability of winter steelhead (Table 1). The remainder of this document elaborates how these results were obtained.

__Table 1__. Probabilities of quasi-extinction over a 100 year period in four populations of Willamette River winter steelhead under four different scenarios. Scenarios with sea lions assume that the predation mortality estimated during that year will continue indefinitely. The lowest predation rate was observed in 2015 and the highest predation rate was observed in 2017.

	Population			
Scenario	N. Santiam	S. Santiam	Calapooia	Molalla
No Sea Lions	0.015	0.048	0.993	0.000
2015 Sea Lions	0.079	0.158	0.998	0.001
Average Sea Lions	0.274	0.335	0.999	0.021
2017 Sea Lions	0.644	0.599	0.999	0.209

Population Viability Analysis

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Population viability analysis (PVA) can be broadly defined as the use of quantitative methods to predict the future status of populations under defined conditions or scenarios. Here, a PVA is used to determine the probability of quasi-extinction over a 100 year period. The PVA scenarios perpetuate observed effects of sea lions at Willamette Falls.

Overview of Method

Sea lions feed on adult salmonids attempting to find passage over Willamette Falls. Mortality of adults during their spawning run is considered to have a density independent effect on subsequent survival rates. This is analogous to harvest mortality. Thus, we can usefully employ common fisheries stock assessment models to capture population dynamics.

With a time series of spawner abundance, spawner age compositions, and mortality due to fishing and sea lions, it is possible to compute the adult recruits (progeny) associated with each year's spawner abundance. Density-dependence in these data can be modeled with Ricker or Beverton-Holt type stock-recruitment functions.

Bayesian analysis uniquely permits probabilistic interpretation of parameter estimates, and the Markov chain Monte Carlo methods used to fit Bayesian models conveniently preserves the covariance structure among parameters. Bayesian methods were therefore used to probabilistically describe parameter uncertainty a stock recruitment relationship.

The estimated stock-recruitment relationship with parameter uncertainty and residual autocorrelation is combined with age composition and adult mortality data. This is sufficient information to project population dynamics through time. The PVA program takes 1000 random draws from the parameter posterior distribution of the best stock recruitment model, and then replicates a 100-year time series 100 times. The total number of simulations where spawner abundance falls below a critical threshold across 4 consecutive year is divided by the total number of simulations (100,000). The result of this computation is the probability of quasi-extinction.

Density Dependence

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Density dependence occurs when demographic parameters (e.g. birth rate or death rate) depend on the density of individuals in the population. For example, as the density (number) of fish increases, competition can cause survival rate to decrease. The form and magnitude of density dependence is a critical component of population dynamics, extinction risk, and optimal harvest rate.

<u>Abundance of Willamette Winter Steelhead</u>

The North Santiam, South Santiam, Calapooia, and Mollala river systems are used to delineate "populations" of winter steelhead. This delineation is consistent with previous conservation and planning efforts (ODFW 2008). Several sources of information were used to construct time series of spawner abundances in these focal populations. A counting station on the fishway at Willamette Falls has produced a time series of annual abundances of winter steelhead dating back to 1946. Since Willamette Falls is below the focal populations, additional information is needed to apportion annual counts at the falls into each population.

A radiotelemetry study conducted in 2013 found that 106 out of 170 tagged fish (62%) reached their maximum migration point within one of the four focal populations (Jepson et al. 2014). This is assumed to reflect spawning distribution because fish were rarely observed to wander among river systems (Jepson 2017 personal communication). Thus we conclude that 38% of the winter steelhead that pass Willamette Falls are not members of the focal populations.

Fish are enumerated at the Minto fish facility in the upper North Santiam and at Foster Dam in the upper South Santiam. These "known fate" individuals were therefore subtracted out of the Willamette Falls count (N_{wf}) to obtain the number of fish whose spawning distribution needs to be determined N_{tbd}:

$$N_{tbd} = N_{wf} * 0.62 - N_{minto} - N_{foster}$$

The quantity N_{tbd} is apportioned to the focal populations based on miles of spawning habitat within each population (L_p) multiplied by the observed redd density ($D_{t,p}$). Note that L_p is temporally static quantity (no time subscript), whereas $D_{t,p}$ varies in time and across populations.

In the North Santiam and South Santiam populations, only spawning habitat mileage below the counting facilities is used because there is already a known number of fish that go above the facility. Let $D_{t,p=NS}$ be the density of redds in year t within the North Santiam (*NS*) population. The population abundance that year is

$$N_{t,NS} = N_{tbd,t}\left(\frac{D_{t,NS} * L_{NS}}{\sum_p^4 (D_{t,p} * L_p)}\right) + Minto\ Count.$$

Observations of redd density have been made at multiple sites within each population since 1985. However, weather conditions and staff workload can prevent observation of redd density at some sites and years. If a given site generally has a high density of redds, then neglecting the site on a given year could give a false appearance of low redd density within the population relative to the years when observation are made at the site. Across all four populations, there are 30 redd survey sites. The date when most surveys began is 1985. There are 30 sites X 32 years = 960 potential observations of redd densities in the redd density data set. However there are 478 actual observations. The extent of missing values is therefore an issue that needs to be resolved so that all available data can be used while also minimizing biases associated with missing values from above average or below average sites.

A multiple imputation technique was developed to infer missing redd densities. Redd survey data from all four populations was combined with the Willamette Falls counts, Minto counts and Foster counts, yielding a matrix with 32 years (rows) and 33 locations (columns). Beginning with the first location, the first year with a missing value was identified. All existing redd densities in that location (across years) were linearly regressed on the redd densities in the next location. A prediction for the missing value was generated, and the log likelihood of the associated statistical model was recorded. A new linear regression was established from the next location, and the model prediction and log likelihood were once again recorded. This repeats across all locations, yielding 32 regressions for a single missing value. A final, model averaged prediction for the missing value was obtained as

$$\widehat{D}_{t,p} = \frac{\sum_i^I \hat{y}_i * w_i}{\sum_i^I w_i},$$

where $\hat{y}_i$ is the model prediction from location *i* and w_i are individual model weights. The w_i are calculated

$$w_i = \frac{e^{-0.5BIC_i}}{\sum_i^I e^{-0.5BIC_i}},$$

where BIC_i is the Bayesian information criterion of regression *i*,

$$BIC_i = 2*nll + k*\log(n),$$

Likelihood

Likelihoods have provided a major theoretical foundation for scientific inference since the work of Ronald Fisher in 1922. Given a probability distribution function, one can find parameter values that maximize the likelihood of observed data. Such parameters are called maximum likelihood estimates, and the likelihood of the observed data given these parameter estimates is a relative measure of the adequacy of the model.

nll is the negative log likelihood, *k* is the number of estimated parameters (3) and *n* is the sample size used in the regression.

Imputed values are not used to impute other values. Imputation of data can be problematic because methods such as the one employed here will artificially reduce the variance of the data. However, this is not a problem in this particular application because the purpose is to merely avoid biasing an average across sites when a particular site has a missing value.
The result of the foregoing methods to apportion Willamette Falls counts of winter steelhead into time series of abundances in the four focal populations is presented in Figure 1.

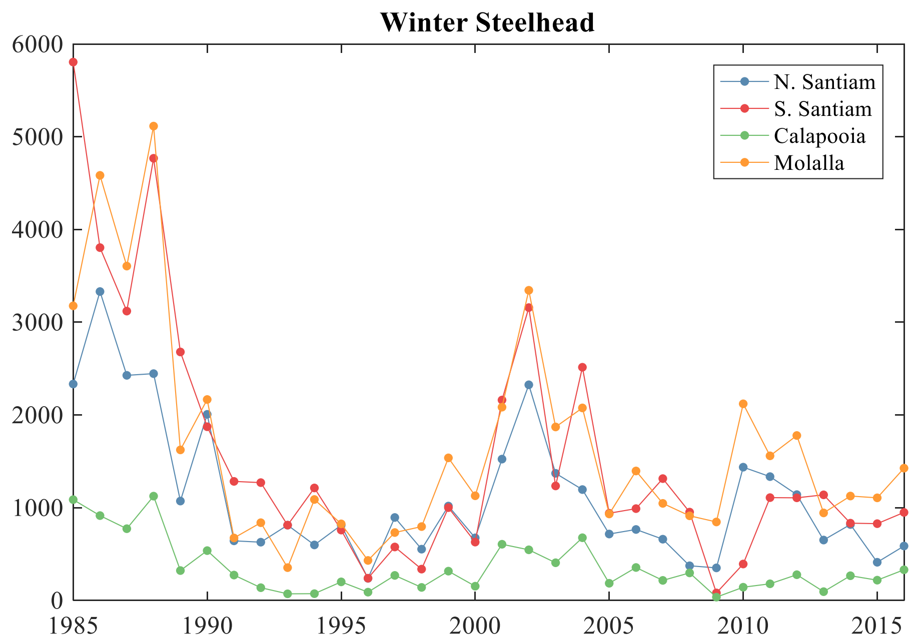

Figure 1. Estimated abundances of wild winter steelhead since 1985. Prior to 1985, it is not possible to apportion Willamette Falls counts because few or zero redd surveys were conducted within each population.

Mortality from Sea Lions

Sea lion predation on salmonids has been rigorously monitored by Wright et al. (2016) since 2014. The estimated number of winter steelhead killed by sea lions in 2014, 2015, and 2016 is 780, 557, and 915 respectively. Wright et al. (2016) note that the 2016 estimate applied to just the "falls strata" whereas monitoring in 2014 and 2015 included the fall and a "river" stratum just below the falls. Using information from years when both strata were monitored, Wright et al. (2016) find that the mortality in the river stratum is 0.385 of the falls plus river. The 2016 winter steelhead estimate in the falls stratum was expanded to a number reflecting mortality in the falls and river strata: 915/(1-0.385) = 1488.

However, as noted in the previous section, 38% of winter steelhead at Willamette Falls are not members of the four focal populations. Thus only 62% of the estimated mortality is on fish that pertain to the focal populations:

$$\begin{bmatrix} 780 \\ 557 \\ 1488 \end{bmatrix} * [0.62] = \begin{bmatrix} 486 \\ 347 \\ 927 \end{bmatrix}$$

An additional adjustment is needed because the mortality estimates pertain only to the time of the monitoring project, yet 23%, 30% and 22% of winter steelhead runs of 2014, 2015, and 2016, respectively, pass through the monitoring area before mortality monitoring begins (Figure 2). A loess quadradic polynomial local regression with span 0.4 was used to smooth daily counts of California sea lions (Figure 3, green). An "interaction index" was computed as the sum of the daily products between the loess smooth of California sea lions (CSL) and counts of winter steelhead (StW) at Willamette Falls:

$$Interaction\ Index = \sum_{day=Feb2}^{June1} CSLsmooth_{day} * StW_{day}$$

The leftmost point of the loess smooth was then extended further to the left (Figure 3, black), reflecting the assumption that California sea lions are present at low densities before the monitoring project began. The interaction index was then recomputed beginning November 1. The ratio between these interaction indices is a factor for expanding sea lion mortality to the entire run of winter steelhead. These factors were computed three times, once for each winter steelhead abundance time series in given in Figure 2. Each factor used the 2016 sea lion information.

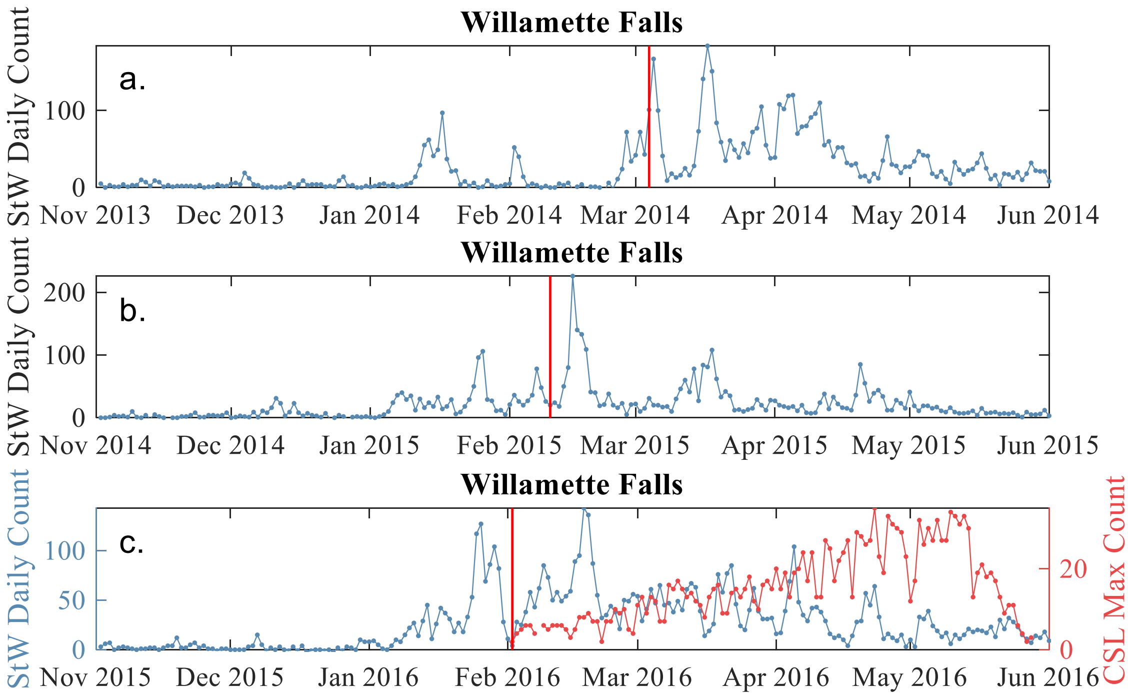

Figure 2. Vertical red bars give the initiation of the California sea lion (CSL) monitoring study relative to the run timing of winter steelhead (StW) at Willamette Falls.

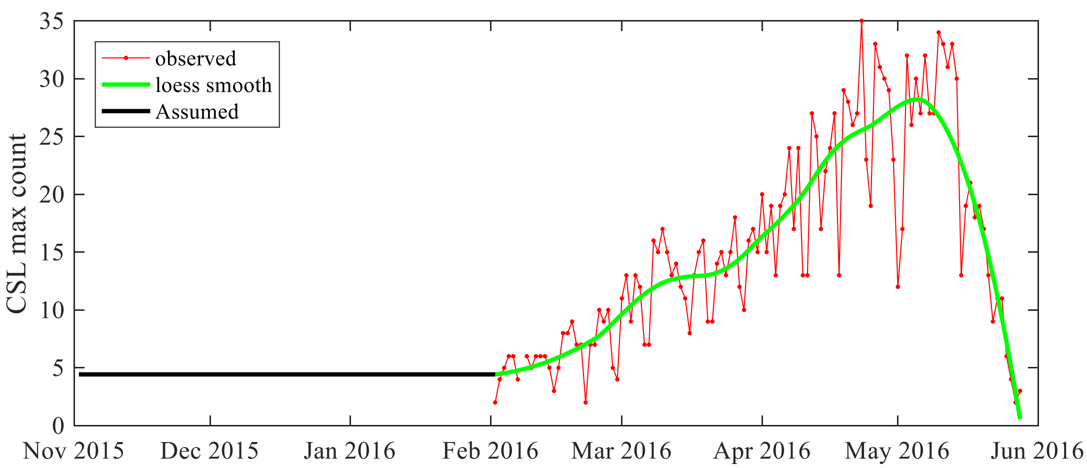

Figure 3. Maximum daily counts of California sea lion (CSL) are identical to Figure 2c.

The factor values are 1.10, 1.14, and 1.09. Even though 23%, 30% and 22% of the steelhead runs went unmonitored for sea lion mortality, expanding for the unmonitored component of the runs adds just 10%, 14% and 9% because California sea lion abundance is relatively low during this time. The final morality estimates for year 2014, 2015, and 2016 are: 486*1.10 = 531, 347*1.14=395, and 927*1.09=1016, respectively.

Wright et al. (2014) note that predation losses of salmonids were generally a few hundred or less at the Falls from the late 1990s through 2003. Starting with 150 salmonid mortalities, we made the same adjustments described above (expand for river stratum, deflate for proportion spawning outside the focal populations, expand by mean of three factors used to correct for early run timing) and then deflated the number again by the mean proportion of all the salmonid mortality during 2014, 2015, and 2016 that are winter steelhead (15%). This computation results in 33 winter steelhead. This amount of mortality was assumed to occur from 1995 through 2003, with linear increase in mortality until the study of 2014, and zero mortality prior to 1995. This time series of mortality is then apportioned to each of the four populations by the relative abundance of fish in each population, as calculated in the previous section. Mortality by California sea lions was 15%, 13% and 24% of the winter steelhead runs in 2014, 2015, and 2016, respectively.

In the spawner-recruit analysis below, the mortality caused by sea lions within each population on year t (denoted M_t) is added into the recruits.

Age Composition of Spawners

Age of spawning fish was determined through scale analysis. There were a total of 784 scales collected from 16 years. The composition of ages on a given year was applied to all populations. When age composition was missing for a given year, the average over all years with age data was used. The matrix of proportions of fish at age = 1,2,3, ..6, on given years (t) is denoted $A_{t,a}$ in the recruitment calculations below.

Angling Mortality

There has not been a directed retention fishery on Willamette River winter steelhead since 1992. Following previous conservation planning efforts (ODFW 2008), harvest rates on winter steelhead in the Willamette River system up through 1992 were assumed to be 21%, then decline to 5% to the present time for incidental mortality in fisheries targeting other stocks. A 2% incidental harvest rate is assumed in the Columbia River for all years. The vector of harvest rates (0.23 through 1993, 0.07 thereafter) it denoted HR_t in the recruitment calculations below.

Proportion of Hatchery-Origin Spawners

Hatchery winter steelhead have not be produced in the Willamette River since the late 1990s. The proportion of hatchery-origin fish spawning in the four focal populations in the 1980s and 1990s has been determined from scale analysis and used in previous conservation planning efforts (ODFW 2008, Appendix B). Specific values for each year and population can be found in the online supplement. Each population's vector of proportions of hatchery-origin spawners in year t is denoted $pHOS_t$ in the recruitment calculations below. This is needed because hatchery-origin fish should not be counted as recruits of the naturally spawning population. The PVA simulates dynamics of naturally spawning fish only.

Spawner-Recruit Analysis

The abundance of naturally produced ("wild") adult recruits associated with fish spawning on year t is

$$R_{S(t)} = \sum_{a=1}^{6} A_{t+a,a}\left(\frac{S_{t+a} * (1 - pHOS_{t+a})}{(1 - HR_{t+a})} + M_{t+a}\right).$$

From here it is possible to fit nonlinear models of the relationship between recruits and spawners. Errors in such models are customarily lognormal, reflecting the multiplicative survival processes that gives rise to uncertainty in the number of recruits.

Bayesian methods were adopted for recruitment modeling for two related reasons. First, Bayesian analysis uniquely yields probabilistic interpretation of parameters. Second, the Markov chain Monte Carlo (MCMC) methods used to fit Bayesian models allow parameter uncertainty to be easily folded into a PVA simulations. JAGS software was used to run the MCMC. JAGS called from MATLAB using matjags.m.

Beverton-Holt models were fitted to these data, but the posterior distribution for the productivity parameters always exactly matched the noninformative priors. These data therefore do not contain sufficient information to reliably identify the Beverton-Holt productivity parameter. A Ricker models were used instead (Table 2). Data from all four populations were combined into a "single" recruitment model. Three such models were constructed that make different assumptions about the across-population independence of parameters (Table 2). Model 1 assumes all parameters, including error variance, are unique in each population. Models 2 and 3 assume that some parameters can be shared across populations. Model 2 assumes there is a single error variance shared by all four populations, but each population has a unique productivity (α) and rate of compensatory density dependence (β). Model 3 assumes that productivity is identical across populations, while the magnitude of compensatory density dependence and error are unique to each population. In all three models, extremely diffuse (noninformative) uniform priors were used for α (Unif(1,200)), β (Unif(0,0.1)), and the standard deviation ε (Unif(0,4)).

Four MCMC chains per model were ran. The first 35,000 iterations were discarded as a "burn-in" period, and 10,000 samples per chain were retained after thinning 1:13 samples from the MCMC. Trace plots of the MCMC were visually inspected for signs of mixing and convergence. Extremely good estimates of the Gelman-Ruben diagnostic ($\hat{R} = 1 \mp 0.0001$) were obtained.

Watanabe-Akaike Information Criterion (WAIC) can be used to assess the relative out-of-sample predictive performance of Bayesian models (Gelman, Whang, and Vehtari, 2013). Each iteration

Table 2. Three Ricker recruitment models fitted to four populations of winter steelhead spawner-recruit data. The models make different assumptions about the number and structure of necessary parameters. WAIC measures relative out-of-sample predictive performance.

ID	Model	# Params	WAIC
1	$R_{t,p} = \alpha_p S_{t,p} e^{-\beta_p S_{t,p}} e^{\epsilon}, \epsilon \sim N(0, \sigma_p)$	12	224.8
2	$R_{t,p} = \alpha_p S_{t,p} e^{-\beta_p S_{t,p}} e^{\epsilon}, \epsilon \sim N(0, \sigma)$	9	248.9
3	$R_{t,p} = \alpha S_{t,p} e^{-\beta_p S_{t,p}} e^{\epsilon}, \epsilon \sim N(0, \sigma_p)$	9	217.6

of the MCMC yields a draw from the multidimensional posterior distribution. This parameter vector can be used to compute the probability density of each datum in the data set. This produces I-by-S matrix of densities, where I is the number of data points (4 populations X 32 years = 128), and S is the arbitrary number of MCMC samples in the posterior. Armed with this matrix, the computed log pointwise predictive density is

$$lppd = \sum_{i=1}^{I} log\left(\frac{1}{S}\sum_{s=1}^{S} p(y_i|\theta^s)\right).$$

A correction for effective number of parameters to adjust for overfitting is obtained with

$$pwaic = \textstyle\sum_{i=1}^{I} V_{s=1}^{S}(\log p(y_i|\theta^s)),$$

where V is the sample variance. Thus *pwaic* is just the posterior variance (across MCMC iterations) of the log predictive density for each data point, summed over all data points, and

WAIC = -2*(*lppd*-*pwaic*).

The units of WAIC can be interpreted like the more familiar AIC and DIC. Specifically, smaller values indicate better models. There are 31.4 units separating model Model 2 and Model 3, indicating that there is no empirical support whatsoever for Model 2 (Table 2). There are 7.3 units separating Model 1 and Model 3, indicating that Model 1 is considerably inferior to Model 3. Model 3 is therefore the only model used hereafter. Hilborn and Waters (1992, page 271-272) argued from first principles that productivities (α) should be similar within a species over much of its range. The model selection results presented here support Hilborn and Walters' (1992) assertion.

The fit of Ricker Model 3 to the spawner-recruit data is given in Figure 4. Uncertainty in Ricker parameters gives rise to multiple potential recruitment functions. Random draws from the MCMC output ensures that parameter values and parameter covariance are obtained in proportion to the associated posterior probability densities.

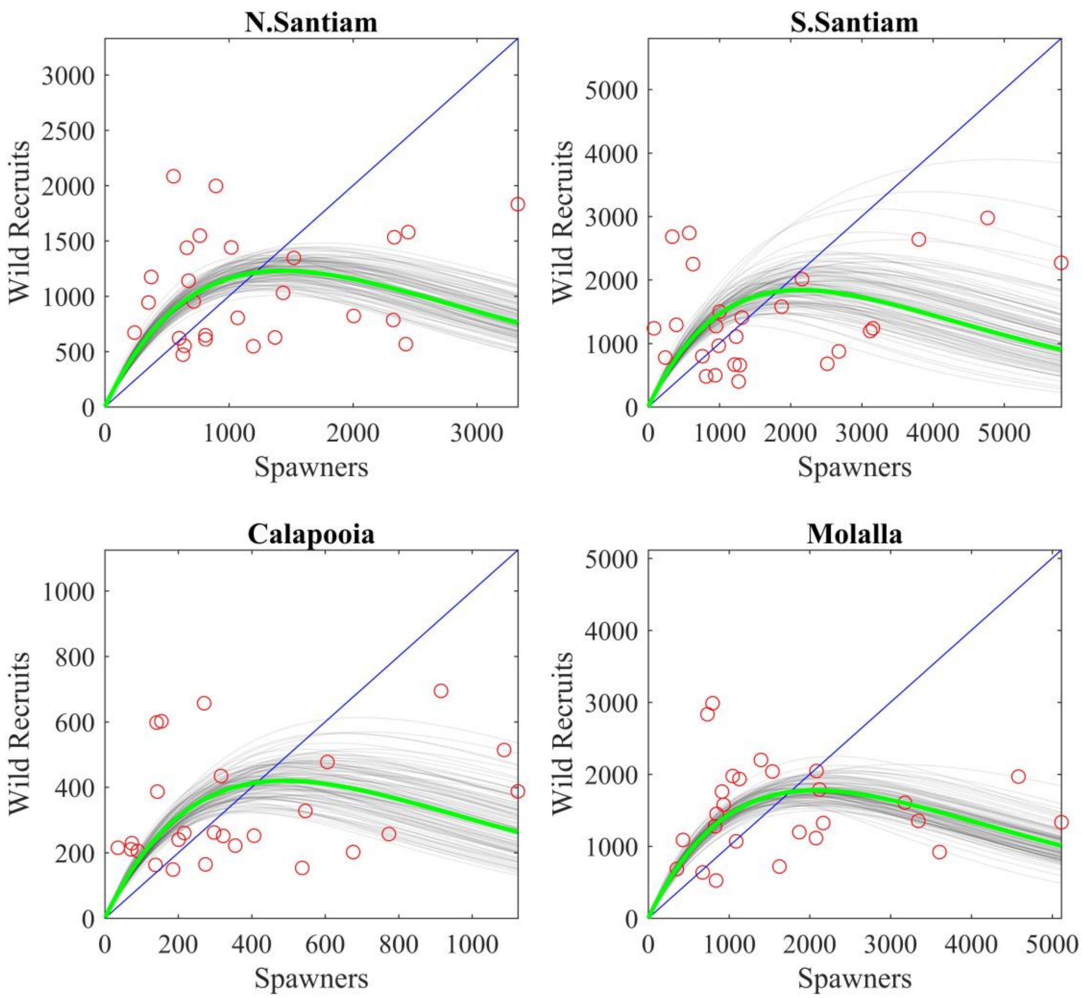

Figure 4. Spawner-recruit data and associated Ricker Model 3 fits. Thick green lines produced from the mean of the parameter posterior distribution. Thin grey lines produced from randomly chosen parameters in the posterior distribution. The blue diagonal line shows the 1:1 relationship between spawners and recruits.

PVA

The population viability analysis (PVA) model use here was also used in a previous assessment of coastal fall Chinook (ODFW 2011). The PVA is a computer model that uses information from the spawner-recruit analysis (see previous section) to project/simulate population abundances into the future. 100,000 repetitions of the 100-year simulation are conducted, and the fraction of these that result in an extinction event yields the probability of extinction. It is important to note that the word "extinction" refers to a population (i.e. "local extinction", or "extirpation"), not a species.

The PVA was ran under four different scenarios for each population. In the scenario called "No Sea Lions" (Table 1) it is assumed that there is no additional mortality beyond the incidental angling mortality during the adult life stage. This assumption holds for all 100 years in the simulation. The scenario called "2015 Sea Lions" perpetuates the lowest mortality rate observed since 2014 for all 100 years of the PVA simulation. The scenario called "2017 Sea Lions" perpetuates the highest mortality rate observed since 2014 for all 100 years of the PVA simulation.

The Ricker recruitment function that is fitted to each population (Model 3) is the model of intergenerational population dynamics that is used within the PVA to simulate spawner abundances through time. However, in the spawner-recruit analysis, "recruits" are defined as pre-angling and pre-sea lion adults. The very same inland mortality estimates that are used to estimate adult recruits from spawner abundances are also used by the PVA to convert adult recruits back into spawners. Indeed, the analytical steps used to estimate recruits for the spawner-recruit analysis are reversed inside the PVA. The PVA

1. takes a given spawner abundance on year t,
2. uses the recruitment function to compute adult recruits,
3. recruits are apportioned across years according to random permutations of the age composition data,
4. recruits are summed across ages within a year and then deflated by harvest rate sea lion mortality (if any).

A critically important aspect of all PVAs is the incorporation of stochasticty ("randomness"). Indeed, if stochasticity is neglected, then the steps outlined above would quickly result in static population and extinction risk would be zero. Stochasticity enters the PVA in several ways. First, the spawner-recruit data are ambiguous with respect to the parameters of the recruitment function (Figure 4). Thus, uncertainty in the estimates of recruitment parameters α and β are simulated within the PVA by repeating simulations with 1000 different values of α and β. The 1000 different values of α and β are selected in proportion to the probabilities of different values and their covariance. This is accomplished by fitting the Ricker spawner-recruit model with MCMC methods in a Bayesian context. Samples of the MCMC are saved, and the PVA randomly selects parameter values out of this pool.

The spawner-recruit data are not fully explained by the Ricker recruitment function, even though parameter uncertainty is acknowledged. In Figure 4, this can be seen as the vertical distances between spawner-recruit "points" and the line(s) representing the recruitment function(s). These "residual" deviations must also be simulated in the PVA. These residuals are lognormally distributed (note that the errors, ε, are exponentiated in the recruitment functions described above) and contain temporal autocorrelation. After the PVA receives a set of values for α and β, the variance of the errors is computed as well as the lag-1 autocorrelation of the errors. A 100-year time series of residual errors is then simulated using:

$$\varepsilon_t = \rho\varepsilon_{t-1} + \sqrt{\sigma^2}\sqrt{1-\rho^2}z_t \ ,$$

where ρ is the lag-1 autocorrelation of the errors, σ^2 is the variance of the errors, and z_t is a standard normal random deviate (Morris and Doak 2002, p. 139). These simulations are repeated 100 times for each of the 1000 random parameter draws. There are therefore 100*1000=100,000 repititions of a 100-year time series.

Extinction in the PVA model occurs when spawner abundance for four consecutive years falls below a "quasi-extinction threshold" (QET). A separate process called "reproductive failure threshold" (RFT) is used to zero-out recruitment at critically low spawner abundances. Both of these thresholds are implemented because processes like inbreeding depression, genetic drift, mate finding, and increased per-capita juvenile mortality will drive the population into extinction at critically low abundances. These negative density-dependent processes are very infrequently observed in nature, so they cannot be cannot be explicitly modeled. Collectively, both QET and RFT represent the boundary of an "extinction vortex" from which real populations are irrecoverable (Gilpin and Soulé1984, Courchamp et al. 2008, Jamieson and Allendorf 2012). The specific values used here are RFT=QET=100. The PVA counts the fraction of the 100,000 simulations where adult abundance falls below QET across 4 consecutive years.

The PVA model uses past abundances to infer extinction risk. Thus, the interpretation of the result is couched in the assumption that the conditions that were present when the data were collected will persist for 100 years. The model is not intended to capture effects of global warming, human population growth, or other anticipated future change. Of course, the future will not be like the past. Future food webs are uncertain, as is the adaptive potential of these fish. The purpose of the PVA is not to forecast the future; rather, the PVA is a comparison of two different sea lion scenarios while holding everything else constant across scenarios.

The PVA needs to replicate observed patterns of variation in spawner abundance. A crude but effective method to determine if the PVA adequately captures observed population dynamics is to simply plot a randomly selected 100 year time series of simulated abundances and then superimpose the empirically observed/reconstructed abundances (Figure 4).   This visual test indicates that the PVA performs well. It simulates abundances that are greater and less than the empirical abundances, the volatility of these deviations seems to match the volatility of the empirical abundances, and the average simulated abundance approximates the average of the empirical abundances.

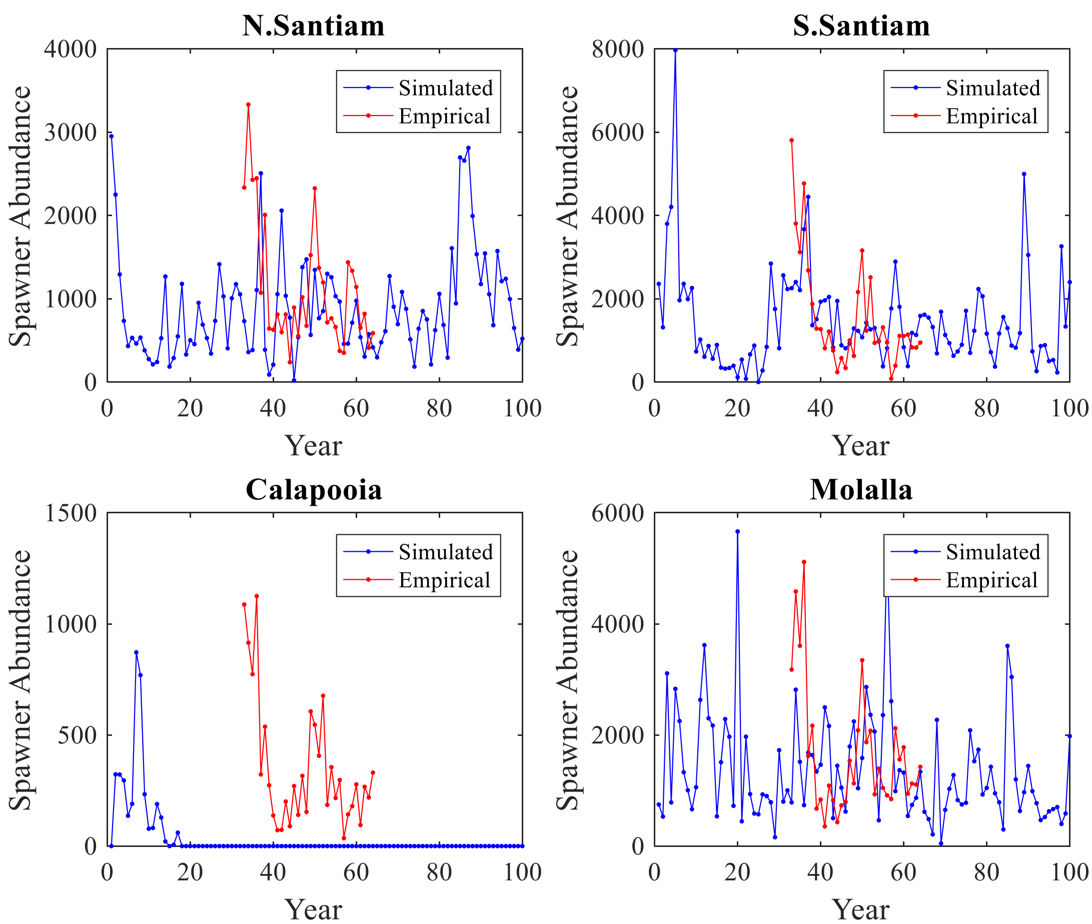

Figure 5. 100 year population simulation from the PVA (blue) with empirical spawner abundance (red). The PVA simulations of spawner abundances resembles the empirical time series.

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